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CYLINDRICAL WARHEAD DESIGN OPTIMIZATION

PROJECTILE, INCENDIARY, AND SELECTED SYSTEMS ANALYSIS BRANCH
WEAPON SYSTEMS ANALYSIS DIVISION

TECHNICAL REPORT AFATL-TR-72-42

MARCH 1972

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Cylindrical Warhead Design Optimization

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FOREWORD

This report documents an in-house effort to develop more flexible computer methodology for optimization or parameterization investigations of the basic design parameters for a cylindrical warhead. The effort was conducted between June and August 1971.

This technical report has been reviewed and is approved.

Thomas P. Christie
THOMAS P. CHRISTIE
Director, Weapon Systems Analysis Division

ABSTRACT

This report documents the Cylindrical Warhead Design Optimization segment of the Weapons Optimization Techniques computer program. This segment enables the user to optimize or parameterize the basic design parameters of a theoretical warhead for a given target or set of targets. The warhead lethality is determined as a function of the basic design parameters: warhead weight, warhead volume, warhead diameter, charge-to-metal ratio, fragment mass, ratio of warhead length to diameter, and fragment height-to-width ratio. This segment can also optimize or parameterize height of burst, terminal velocity, impact angle, and fragment spray angle.

TABLE OF CONTENTS

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SECTION I

INTRODUCTION

Cylindrical Warhead Design Optimization (CYDOP) is a segment of the Weapon Optimization Techniques (WOPS) computer program. The WOPS program (Reference 1) was written by the Martin Marietta Corporation and was presented to the Air Force Armament Laboratory (AFATL) in October 1967. Initially, the program optimized specific warhead and delivery parameters of fragmentation, blast, and fragmentation/blast warheads for materiel and personnel targets for which lethal area is a measure of effectiveness. Since that time, WOPS has been modified several times, and at the date of this report, CYDOP is the most recent of these modifications.

The first WOPS modification (Reference 2) was a part of a follow-on contractual effort. The contractor modified WOPS to increase program flexibility and to maintain state-of-the-art technology. The main feature of this modification is the capability to optimize warheads with varying charge-to-metal ratios. Other improvements include the incorporation of the fragment shape (k) factor, the capability to input special drag coefficient tables, the capability to compute munition lethal area against troops in foxholes, and the computation of minimum effective fragment velocities for personnel and materiel targets by recent state-of-the-art technology.

In September 1969, a second modification (Reference 3) to the WOPS program was completed by the contractor. This modification enables the optimization of bomblet pattern size and the evaluation of the kill probabilities of warheads emitting a high velocity plane of fragments.

Three modifications, in addition to those prepared by the contractor, have been incorporated into the WOPS program by AFATL. The program was first modified to receive warhead and target data from magnetic tapes. The second modification gave the capability of using only one input deck to evaluate similar cases in the same computer job and also a method of changing those data that vary from case to case. At the date of this report, the third modification is under development. Once completed, the program will be capable of parameterizing lethal area when optimizing bomblet pattern size so that its sensitivity to lethal area can be analyzed.

The WOPS program assumes that the basic design of the warhead is known prior to program execution. Such warhead characteristics as fragment fly-off velocity, fragment density, and fragment presented area must be input to the program. WOPS can assist in the design of warheads only in that it can determine the optimal fragment mass and the optimal extremes of the fragment spray angle for a given target spectrum. Often it is necessary

to perform analyses to determine the optimal parameters of a theoretical warhead. When a warhead is in the design stage, the characteristics are not known but must be calculated externally and input to the program. The Cylindrical Warhead Data (CYNDAT) program was written to perform these calculations.

CYNDAT uses basic design parameters to compute dimensions and explosive characteristics of theoretical warheads. Prior to the CYDOP modification, it was necessary to use the CYNDAT output as the input to WOPS. Moreover, for each set of CYNDAT outputs, one run of WOPS had to be made. After the CYDOP modification, the final answer can be obtained in one computer run.

This report documents those segments of CYDOP that differ from WOPS. The documentation consists of Section II User Section, Section III Analyst Section, and Section IV Test Case. The User Section contains a brief description of the program and an explanation of the data input formats. The Analyst Section discusses the theory, the FORTRAN-source statements, and flow charts. Section III illustrates the input and gives an interpretation of the output to a test case. Appendix I presents the utilization report to be used with Section II. Appendixes II and III discuss the Gurney equation correction factor and the polar zone assumption, respectively, used in Section III.

SECTION II

USER SECTION

CYDOP is the last of three warhead input segments to the WOPS program. The first describes the input for a warhead with constant charge-to-metal ratio, and the second concerns input data for a warhead with varying charge-to-metal ratio. The CYDOP segment uses basic design parameters to compute lethal area so that the optimal set of warhead parameters can be determined.

The CYDOP segment assumes that the warhead is cylindrical in shape and is primarily a fragmentation bomb. Due to the methodology employed, the warhead must have single-end initiation. Furthermore, the warhead must assume a fuze-first orientation before detonation.

Assuming that these conditions exist, the first step in executing the WOPS program with the CYDOP segment is to determine the constraints defining the warhead. Next, based on these constraints, the user must select three independent variables from the following set of warhead parameters: weight, volume, diameter, warhead length-to-diameter ratio, and charge-to-metal ratio.

The user can then optimize or parameterize any number of the three selected warhead parameters, the two fragmentation parameters (fragment mass and fragment height-to-width ratio), and the standard warhead parameters (height-of-burst, velocity of the missile, terminal warhead attack angle, and upper limit of the first polar zone). Finally, the output can be analyzed to determine the optimal set of parameters for the warhead.

The complete, updated version of the utilization report for the WOPS program is presented in Appendix I. The format is the one used by the Freeman Mathematical Laboratory at Eglin Air Force Base. The program user should refer to this utilization report while compiling the data deck input.

The utilization report is divided into Constants, Warhead, and Target Sections. The Constants Section (Section I) consists of four cards that are used to define the basic parameters describing a warhead-target situation. The Warhead Section (Section II) is partitioned into three subdivisions, only one of which may be used in a given run. The first subdivision (Section IIA) concerns the input data of warheads with constant charge-to-metal ratios. The second subdivision (Section IIB) concerns the input data of warheads with varying charge-to-metal ratios. The third (Section IIC) describes the input cards used in designing a theoretical warhead. The Target Section (Section III) concerns the input cards that describe the target. This report is primarily concerned with only Sections I and IIC.

The execution card deck required to execute the modified WOPS program on the CDC 6600 computer is shown in Figure 1. The data deck which appears at the end of the execution deck is shown in Figure 2.

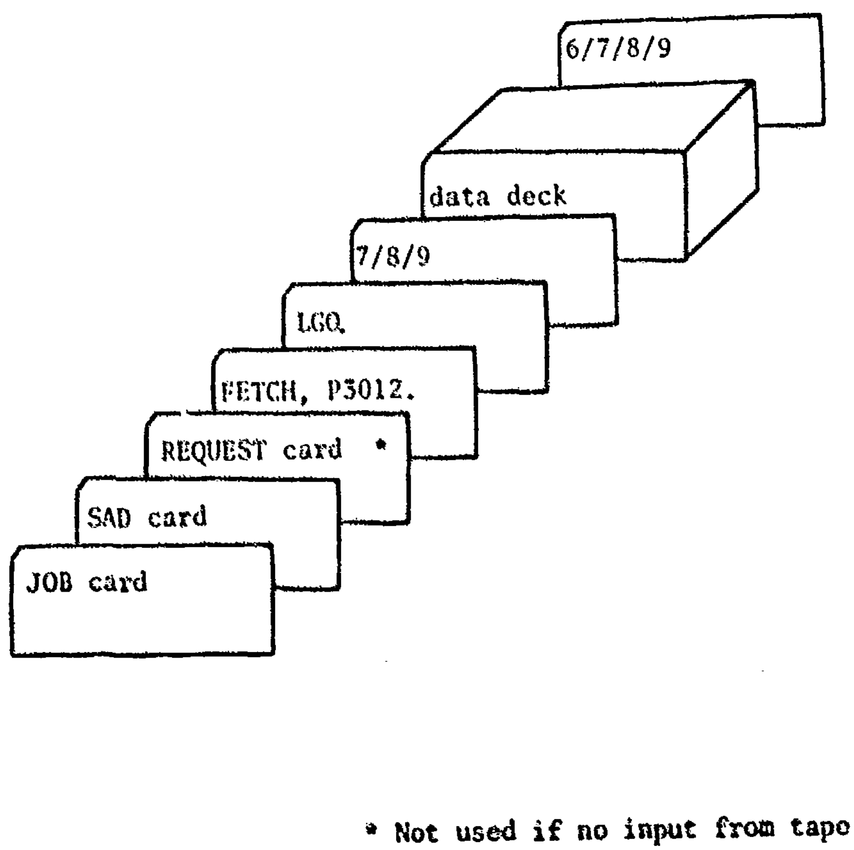
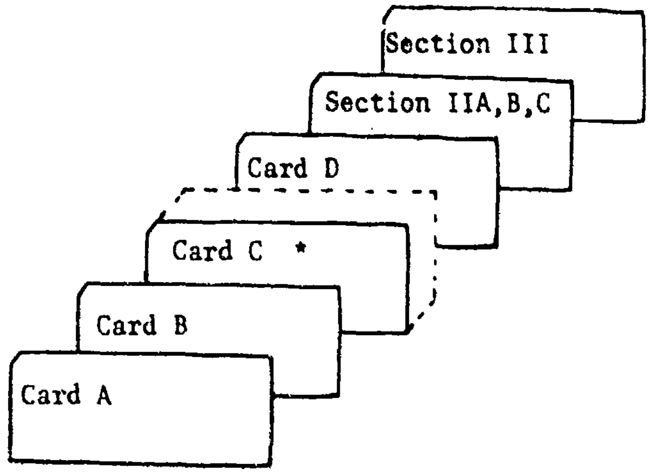


Figure 1. Execution Deck for Modified WOPS Program



* Repeated for each variable optimized

Section III deals with target data input.

Section IIA deals with warheads which have a constant charge to metal ratio.

Section IIB deals with warheads which have a varying charge to metal ratio.

Section IIC deals with warhead design. The following is an illustration of its make-up:

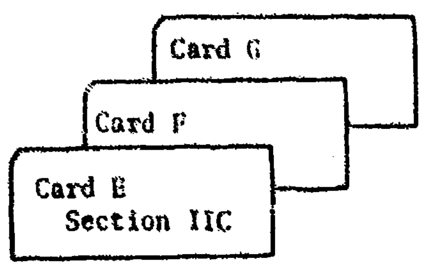


Figure 2. Data Deck for Modified WOPS Program

SECTION III

ANALYST SECTION

1. THEORY

In Section I, it was pointed out that a choice of warhead design parameters had to be made. This choice is necessary because there are five design parameters of interest, only three of which are needed to determine a solution to warhead design equations. Therefore, the CYDOP modification is divided into 10 segments to process the 10 combinations which result from five variables taken three at a time. Table I illustrates these 10 combinations. Table II is a listing of the variable names.

TABLE I. COMBINATIONS OF THE FIVE DESIGN PARAMETERS

Possible Combinations			Combination Number
Weight	Charge to metal	Length to diameter	1
Weight	Charge to metal	Diameter	2
Weight	Length to diameter	Diameter	3
Weight	Length to diameter	Volume	4
Weight	Diameter	Volume	5
Charge to metal	Length to diameter	Diameter	6
Charge to metal	Length to diameter	Volume	7
Charge to metal	Diameter	Volume	8
Volume	Weight	Charge to metal	9
Volume	Diameter	Length to diameter	10

The last two combinations listed in Table I do not uniquely determine a solution to warhead design equations; therefore, they can not be used. However, the first eight are sufficient to describe any set of warhead constraints.

TABLE II. VARIABLE NAMES

Variable Name	Description	Units
D	diameter of explosive in the case	in
DV	detonation velocity of the explosive	ft/sec
DWH	diameter of warhead	in
FM (1,1)	fragment mass	grains
FV (1,1)	fragment fly-off velocity	ft/sec
GAMMA (or γ)	Gurney equation correction factor	
GC (or $\sqrt{2E}$)	Gurney constant for the explosive	ft/sec
HF	height of the fragments	in
KDGN	design mode flag	
NCOMB	combination number	
RCM (or C/M)	ratio of charge to metal	
RHOEX	density of the explosive	lb/cu.in.
RHOSTL	density of the metal	lb/cu.in.
RHW (or H/W)	ratio of fragment height to width	
RLD (or L/D)	ratio of warhead length to diameter	
TFRAG	total number of fragments	
THCK	thickness of fragments	in
THET	constant spray angle	deg
THETAA	computed spray angle	deg
WC	weight of the case	lb
WE	weight of the explosive	lb
WF	width of the fragments	in
WHL	warhead length	in
WVOL	warhead volume	cu. in.
WWT	warhead weight	lb

Consider, for example, combination number 1 (Table I). The two unknown variables, diameter and volume, are functions of the three known parameters. That is

$$DWH = f(WWT, C/M, L/D)$$

and

$$WVOL = f(WWT, C/M, L/D).$$

However, in combination number 9, neither the length-to-diameter ratio nor the warhead diameter can be represented in terms of the three known variables. That is

$$L/D \neq f(WWT, C/M, WVOL)$$

$$DWH \neq f(WWT, C/M, WVOL).$$

Similarly for combination 10,

$$WWT \neq f(L/D, DWH, WVOL)$$

$$C/M \neq f(L/D, DWH, WVOL).$$

It now remains to derive each equation for these combinations. This will be done in combination number order by solving for the two unknown variables in terms of the three known variables. In the following equations, RHOSTL, RHOEX, and π are constant.

The following basic equations were used:

$$C/M = \frac{WE}{WC} \tag{1}$$

$$WWT = WE + WC \tag{2}$$

$$WVOL = \frac{WE}{RHOEX} + \frac{WC}{RHOSTL} \tag{3}$$

$$L/D = \frac{WHL}{DWH} \tag{4}$$

$$DWH = D + 2(THCK) \tag{5}$$

$$WVOL = \pi\left(\frac{DWH}{2}\right)^2 WHL \tag{6}$$

1) Given: WWT, C/M, L/D
Find: DWH, WVOL

From equations (1) and (2), the weight of the case is

$$WC = \frac{WWT}{C/M + 1}, \tag{7}$$

and the weight of the explosive (WE) is obtained by rearranging equation (1).

From equation (6),

$$WVOL = \frac{\pi}{4}\left(\frac{WHL}{L/D}\right)^2 WHL = \frac{\pi}{4} \frac{WHL^3}{(L/D)^2} \tag{8}$$

So,

$$WHL = \sqrt[3]{\frac{4}{\pi}(L/D)^2 \, WVOL} \tag{9}$$

Combining equation (3) and (9) gives

$$WHL = \sqrt[3]{\frac{4}{\pi}(L/D)^2 \left(\frac{WE}{RHOEX} + \frac{WC}{RHOSTL}\right)} \tag{10}$$

The diameter (DWH) can now be determined by rearranging equation (4), and the volume (WVOL) can be determined from equation (6).

2) Given: WWT, C/M, DWH
Find: WVOL, L/D

The weight of the case (WC) and the weight of the explosive (WE) are obtained from equations (7) and (1), respectively. So, the warhead volume (WVOL) can readily be determined from equation (3).

The length of the warhead (WHL) can be determined by rearranging equation (6). Then, the ratio of length to diameter is given by equation (4).

3) Given: WWT, '/D, DWH
Find: WVOL, C/M

The warhead length (WHL) can be determined by rearranging equation (4), and the volume is given by equation (6).

The charge-to-ma: t ratio is a function of the warhead weight and the weight of the case (or the weight of the explosive). So, the weight of the case must be determined first. From equations (3) and (2),

$$WVOL = \frac{WC}{RHOSTL} + \frac{WWT-WC}{RHOEX} \tag{11}$$

Upon rearranging terms,

$$WC = \frac{RHOSTL(WVOL \cdot RHOEX-WWT)}{RHOEX-RHOSTL} \tag{12}$$

The charge-to-metal ratio is then given by,

$$C/M = \frac{WWT-WC}{WC} \tag{13}$$

4) Given: WWT, L/D, WVOL
Find: DWH, C/M

From equations (6) and (4),

$$WVOL = \pi\left(\frac{DWH}{2}\right)^2 \left(L/D\right) DWH = \frac{\pi}{4} (DWH)^3 (L/D) \tag{14}$$

So,

$$DWH = \sqrt[3]{\frac{4}{\pi}\frac{WVOL}{L/D}} \tag{15}$$

Using equation (12), the charge-to-metal ratio can be determined,

$$C/M = \frac{WWT-WC}{WC} \tag{16}$$

5) Given: WWT, DWH, WVOL
Find: L/D, C/M

From equation (15),

$$L/D = \frac{4}{\pi}\frac{(WVOL)}{(DWH)^3} \tag{17}$$

Using equation (12), the charge-to-metal ratio can be determined as in equation (13).

6) Given: C/M, L/D, DWH
Find: WVOL, WWT

The warhead volume (WVOL) is determined using equation (14). From equations (1) and (3),

$$\text{WVOL} = \frac{\text{WC}}{\text{RHOSTL}} + \frac{\text{WC}(\text{C/M})}{\text{RHOEX}} = \text{WC}\left(\frac{1}{\text{RHOSTL}} + \frac{\text{C/M}}{\text{RHOEX}}\right) \qquad (18)$$

Therefore,

$$\text{WC} = \frac{\text{WVOL}}{\dfrac{1}{\text{RHOSTL}} + \dfrac{\text{C/M}}{\text{RHOEX}}} \qquad (19)$$

From equations (1) and (2),

$$\text{WWT} = \text{WC} + \text{WC}(\text{C/M}) = \text{WC}(1 + \text{C/M}) \qquad (20)$$

7) Given: C/M, L/D, WVOL
Find: DWH, WWT

The diameter is given by equation (15), the weight of the case is given by equation (19), and the warhead weight is given by equation (20).

8) Given: C/M, DWH, WVOL
Find: L/D, WWT

The ratio of length to diameter is given by equation (17). Warhead weight is given by equations (19) and (20).

After one of the eight combinations is executed, the following warhead variables are determined: weight, volume, diameter, length, charge-to-metal ratio, length-to-diameter ratio, weight of the case, and weight of the explosive. The two fragmentation variables (fragment mass and fragment height-to-width ratio) are also determined since they were input. It is then necessary to compute the remaining warhead and fragmentation parameters from these known variables. These equations will be derived in the following paragraphs.

Fragment fly-off velocity is determined by the Gurney formula (derived in Reference 4). The equation, for cylindrical warheads, is

$$\text{FV} = \sqrt{2E}\sqrt{\frac{\text{C/M}}{1 + 0.5(\text{C/M})}} \qquad (21)$$

where $\sqrt{2E}$ is a characteristic value of the explosive, called the Gurney constant.

There has been much discussion concerning the accuracy of the Gurney equation. In Reference 5, a set of data points for correction to the Gurney formula is presented as a function of length-to-diameter ratio. In Appendix II, an exponential curve was fitted to these data points using the least squares method. The equation for the correction factor, γ, was found to be

$$\gamma = 1.0 - (0.4486)\exp[-1.2345(L/D)] \tag{22}$$

This is used as a multiplier to the Gurney equation, so that the final form of the Gurney equation is

$$FV = \gamma \sqrt{2E} \sqrt{\frac{C/M}{1 + 0.5(C/M)}} \tag{23}$$

The diameter of the explosive, D, is used in computing the spray angle and the fragment thickness. The equation for D is derived in the following manner:

$$\begin{aligned} WE &= Vol_{(expl)} \; RHOEX \\ &= \pi\left(\frac{D}{2}\right)^2 (WHL) \; RHOEX \\ D^2 &= \frac{4(WE)}{\pi \; (WHL) RHOEX} \\ D &= 2\sqrt{\frac{WE}{\pi (WHL) RHOEX}} \end{aligned} \tag{24}$$

The thickness of the fragments, which is also the thickness of the case, is given by

$$THCK = \frac{DWH-D}{2} \tag{25}$$

The fragments are assumed to be controlled, rectangular parallelepipeds. The width of the fragments is given by

$$\begin{aligned} FM &= Vol_{(frag)} \; (RHOSTL) \; (7000) \\ &= THCK(WF)(HF)(RHOSTL) \; (7000) \\ &= THCK(WF)^2(H/W) \; (RHOSTL)(7000) \end{aligned} \tag{26}$$

$$WF = \left(\frac{FM}{(7000)(THCK)(H/W)(RHOSTL)} \right)^{1/2} \tag{27}$$

Where 7000 is a factor converting pounds to grains.

The total number of fragments is determined by dividing the weight of one fragment into the total weight of all the fragments,

$$TFRAG = \frac{(7000)WC}{FM} \tag{28}$$

In reality, TFRAG should be an integer since there should be an integral number of fragments in a warhead of given length and diameter, but this fact is ignored here since the error is small.

The fragment presented area, used in drag calculations, is defined as one-fourth the surface area.

$$\begin{aligned} FPA &= \frac{1}{4} [2(WF)HF + 2(WF)THCK + 2(HF)THCK] \\ &= \frac{1}{2} [WF(HF) + WF(THCK) + HF(THCK)] \end{aligned} \tag{29}$$

Since in the program the fragment height, width, and thickness are in inches and the fragment presented area is in square feet, equation (29) must be divided by 144. So

$$FPA = \frac{1}{288} [WF(HF) + WF(THCK) + HF(THCK)] \tag{30}$$

Only one polar zone is assumed for the theoretical warhead. The lower polar zone angle is chosen as 90°, or the angle measured between the warhead longitudinal axis and a line perpendicular to that axis (Figure 3). The upper polar zone angle is computed and, in general, is 90° plus an acute angle.

The upper polar zone angle is computed by one of three methods: (1) the angle is allowed to vary by optimizing or parameterizing the upper polar zone angle, (2) the angle is computed as a function of warhead characteristics, or (3) the angle is input and held constant. The first and third of these methods are self explanatory. The second method utilizes Shapiro's formula (derived in Reference 5):

$$\text{THETAA} = \tan^{-1} \left\{ \frac{FV(WHL)}{2(DV)\,[WHL^2 + (D/2)^2]^{1/2}} \right\} \tag{31}$$

After computing THETAA by one of these three methods, the upper polar zone angle, THSUR, can then be defined as

$$\text{THSUR} = \frac{\pi}{2} + \text{THETAA} \tag{32}$$

Shapiro's formula actually computes the upper spray angle of a single end initiation bomb (α in Figure 3). However, the program makes the assumption that representing this angle by an angle with its vertex at the center of the warhead (θ in Figure 3) does not cause a significant degree of error. Appendix III contains a discussion of this assumption.

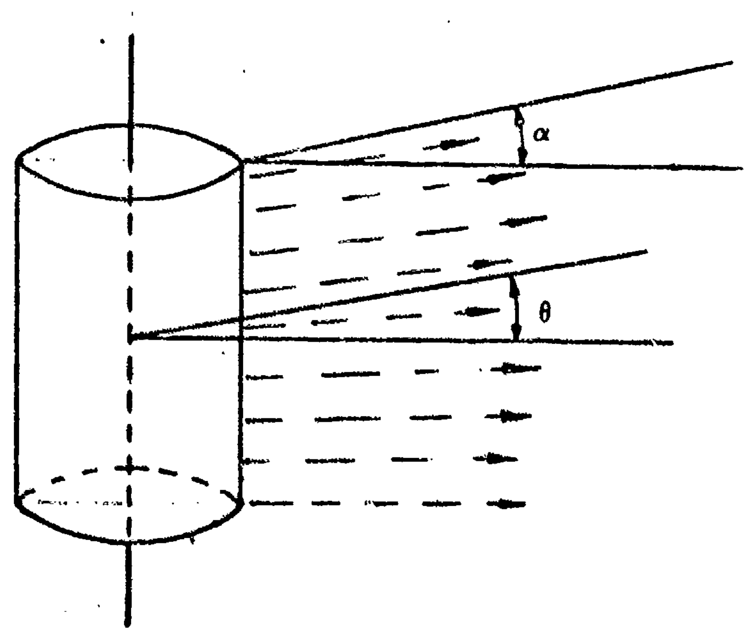


Figure 3. Polar Zone Representation

2. ILLUSTRATION OF FORTRAN STATEMENTS

The WOPS program is divided into one mainline, four overlays, and 15 subroutines. The CYDOP modification directly affects only two overlays and one subroutine. These segments will be discussed (flow charts shown in Figures 4 to 6).

The input overlay (OVERLAY 1) is the first segment of the program affected by the CYDOP modification. The first card read by this overlay is in the input card type D. The last variable read on this card is KDGN, the design mode flag.

```
C         READ CARD TYPE D
   80 READ (5, 2)  IPRNT1,IPRNT2,IPRNT3,IPRNT4,IPRNT5,IDUMY,INDXR,
     1             IDUM ,DGRID,ALPHAD,ZB,VM,RGMAX,WDIS,KDGN
    2 FORMAT(5I1,3I5,4F10.0,2F5.0,I5)
C         KDGN = 1  --  FLAG FOR DESIGN MODE
      IF(IPRNT5.EQ.1) WRITE(6,504) KDGN
  504 FORMAT(/,1X,*KDGN =*,I5)
```

If KDGN=1, the program is to be executed in the design mode, and the program assumes that input Section IIC will follow. If IPRNT5=1, the program checkout print indicator, the program will print the value of KDGN.

In the next set of statements that pertain to the design mode, the first FORTRAN statement determines if the program is used for design. If KDGN ≠ 1, the program skips the design input. If KDGN = 1, the program reads three input cards:

```
      IF(KDGN.NE.1) GO TO 510
C ----- INPUTS IN DESIGN MODE --  INPUT TABLE IIC ----
C         READ CARD TYPE E
      READ(5,1) WTITLE
    1 FORMAT (12A6)
C         READ CARD TYPE F
      READ(5,501) RHOEX,RHOST  ,GC,DV,THET,NCOMB
  501 FORMAT(5F10.0,I5)
      IF(RHOST . GT. 0.) RHOSTL = RHOST*12.096E6
C         READ CARD TYPE G
      READ(5,502) WVOL,WWT,DWH,RLD,RGM,RHW,FM(1,1)
  502 FORMAT(7F10.0)
```

The first card contains the warhead title. The second contains values of parameters that depend on the type of explosive and the type of metal used. Also included on the second card is the combination number, NCOMB, and the spray angle, THET, if it is held constant. The third card contains values of design parameters that the user wishes to hold constant throughout the program. If the field for a particular variable is left blank, then it is assumed that the value of that variable will vary.

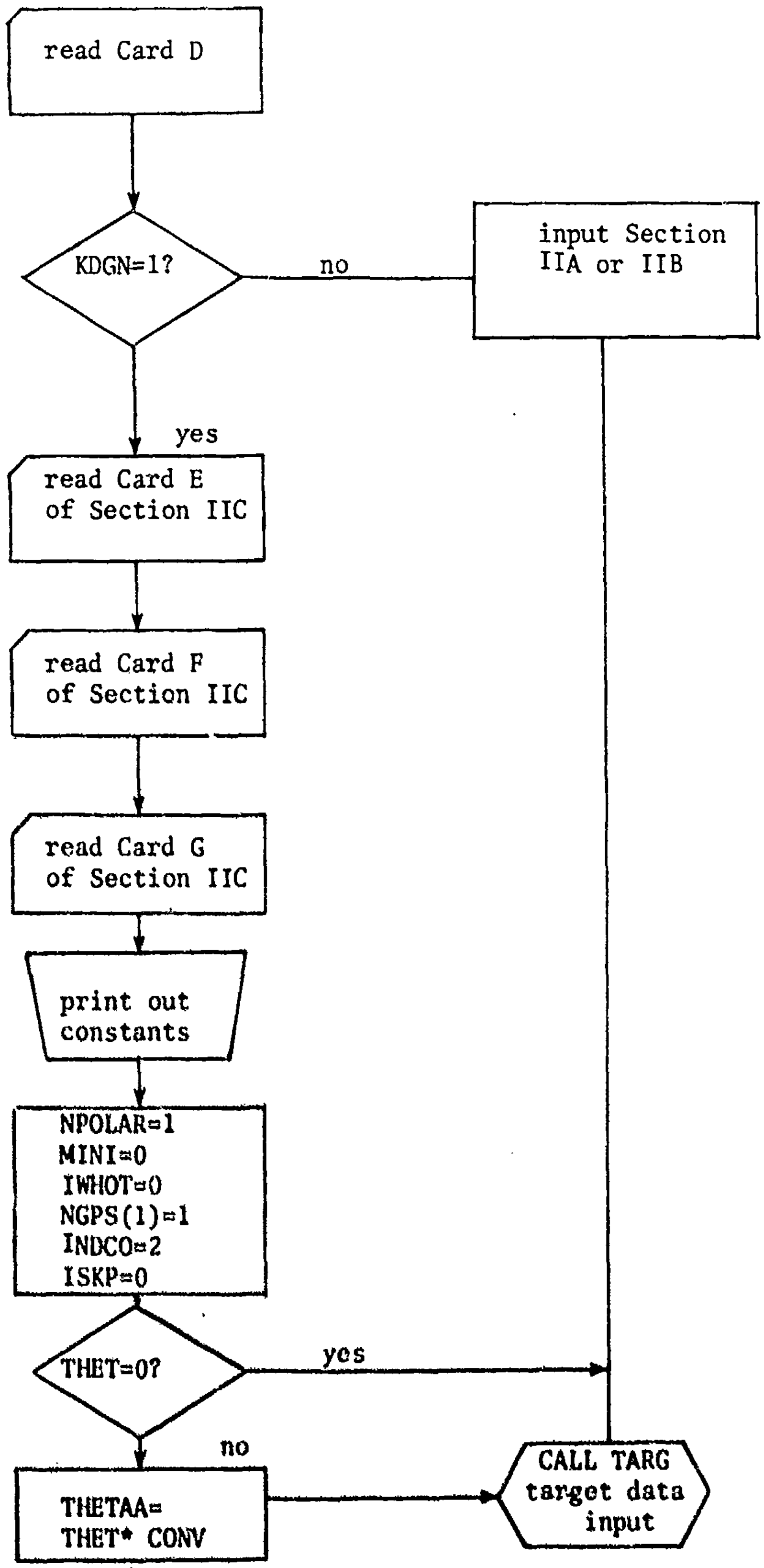


Figure 4. Flow Chart - Input

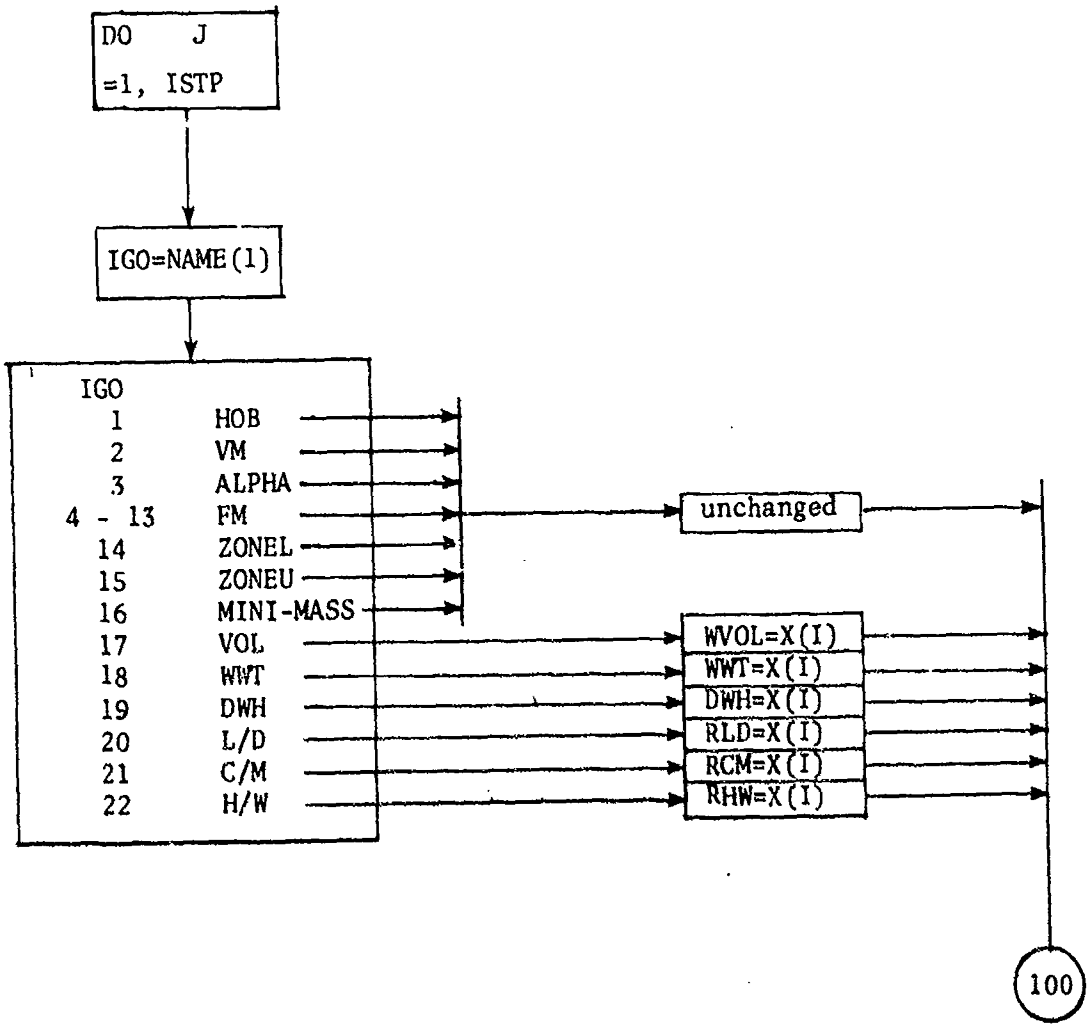


Figure 5. Flow Chart - Computation

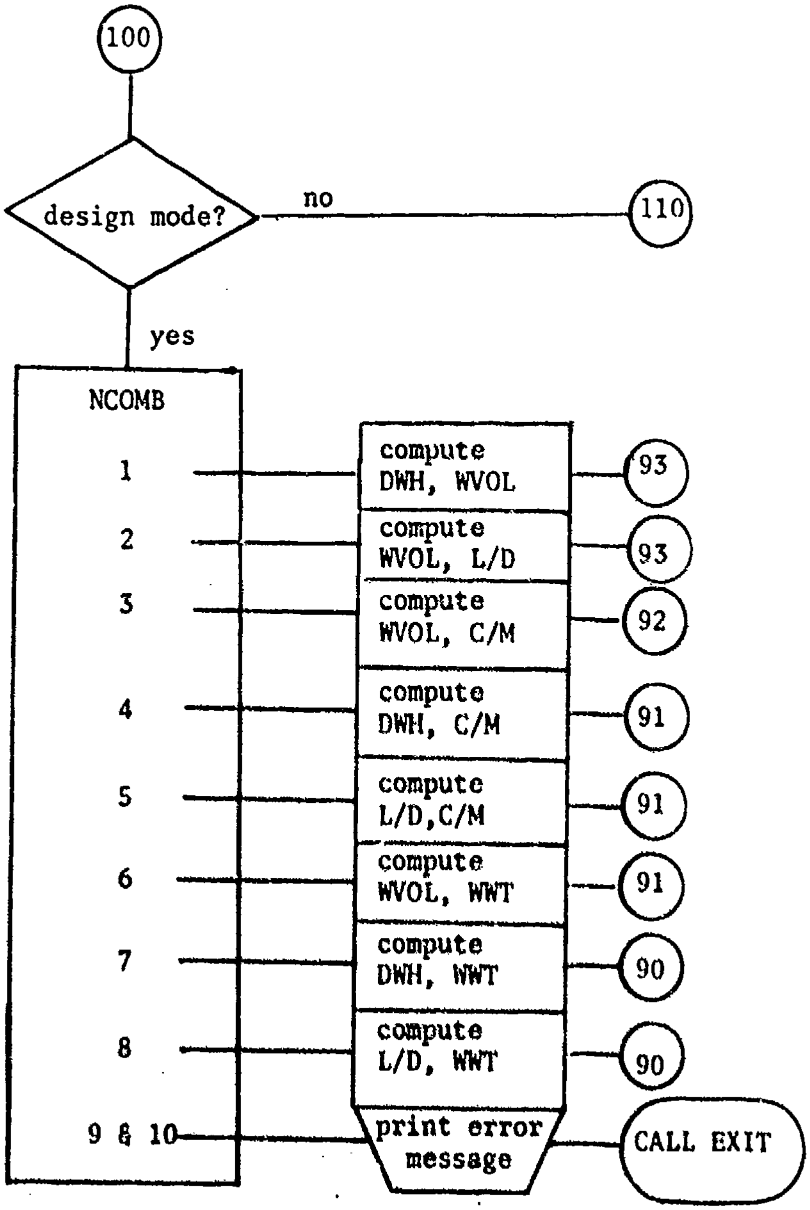


Figure 5. Continued

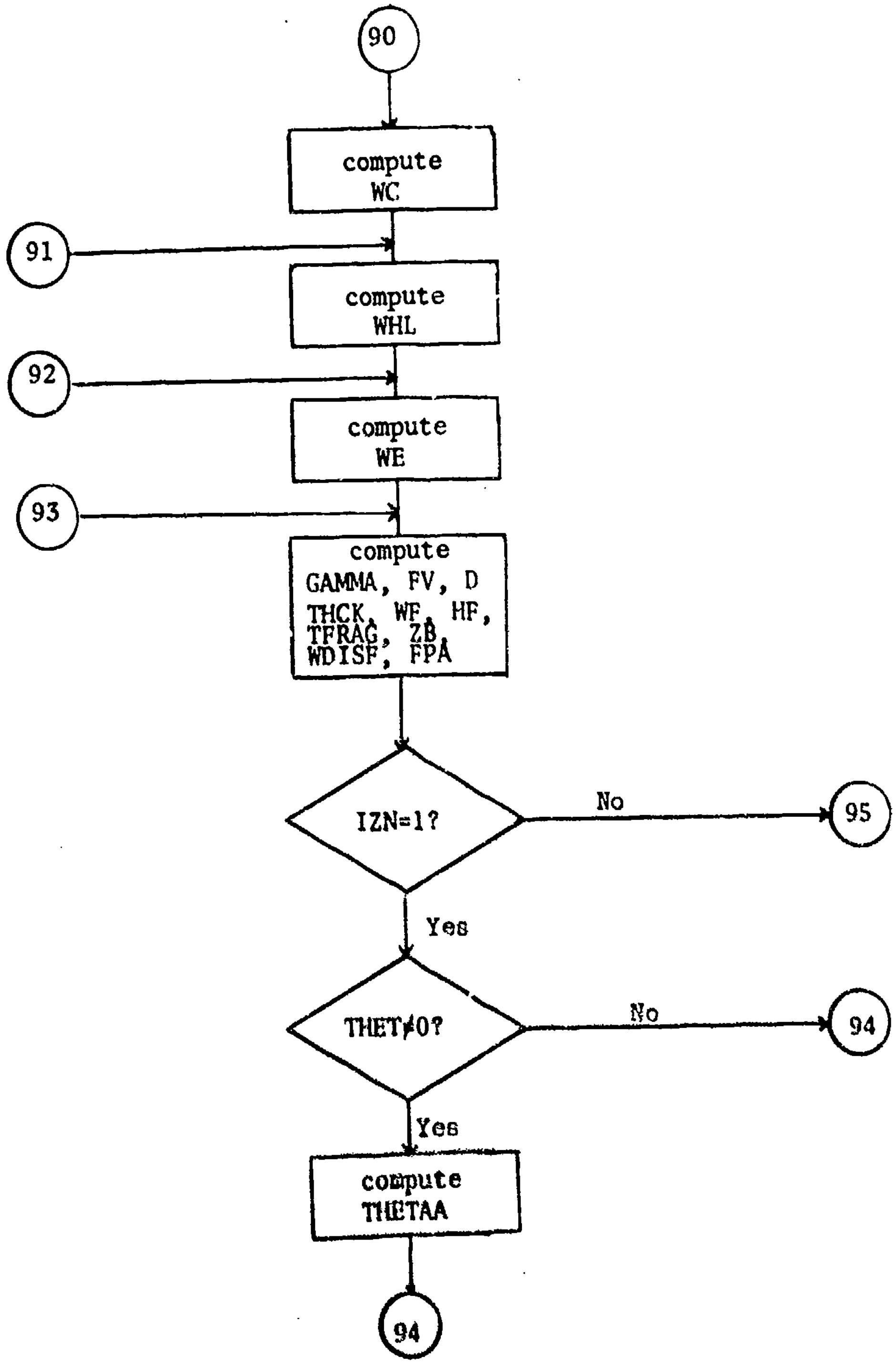


Figure 5. Continued

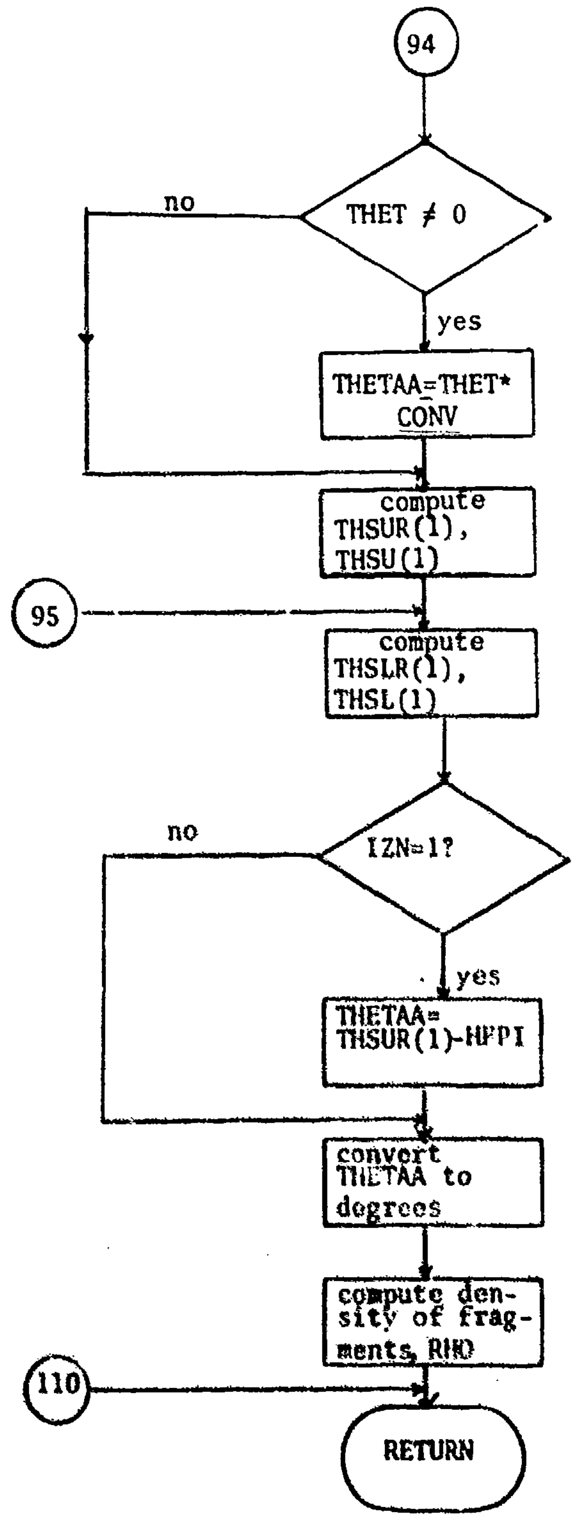


Figure 5. Concluded

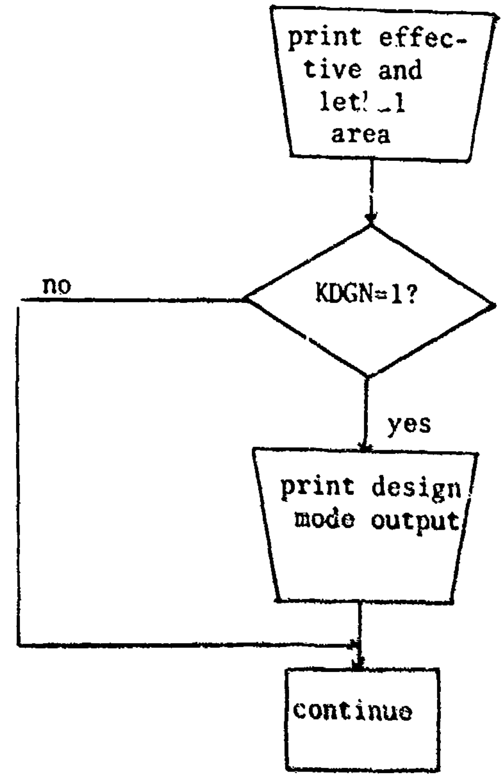


Figure 6. Flow Chart - Output

The next set of statements immediately follow and cause the program to print out the constant values that were input.

```
C         OUTPUT CONSTANTS IN DESIGN MODE.
      WRITE(6,503) NCOMB,RHOEX,RHOSTL,GC,DV,THET,WVOL,WWT,DWH,RLD,RCM,
     1 RHW,FM(1,1)
  503 FORMAT(///,2X,*COMB     RHO EX      RHO M   GURNEY C    DET VEL       TH
     1ETA          VOL          WT          DWH          R/L          C/M          H/W
     2      FM*,/,1X,I5,12F10.3,/)
```

Several variables have to be initialized before continuing the program:

```
C       SET CONSTANT PARAMETERS IN DESIGN MODE
      NPOLAR = 1
      MINI = 0
      IWHDT = 0
      NGPS(1) = 1
      INDCD = 2
      IF(THET.NE. 0.) THETAA = THET*CONV
      ISKP = 0
C       END DESIGN MODE INPUT SECTION. GO TO TARGET INPUT SECTION
      GO TO 400
  510 CONTINUE
```

NPOLAR = 1, defines the number of polar zones as one. MINI = 0 indicates that the warhead does not contain a plane of fragments. IWHDT = 0 means input Section IIB is not used. NGPS (1) = 1 indicates that the number of classes of fragments in the first(and only) polar zone is one. INDCD = 2 indicates that the drag table for cubes is used. If the spray angle is to be held constant, the spray angle is set equal to the constant input value. CONV is a conversion factor to convert degrees to radians. ISKP = 0 initializes the target input file number. GO TO 400 causes the program to skip over the statements used to input standard warhead data (input Sections IIA and IIB). 510 CONTINUE is the last statement in this segment; it is used as a reference point if the design input is skipped over.

The next segment of the program affected by the CYDOP modification is a computation section, SUBROUTINE MOVE. This subroutine is primarily concerned with assigning the new values of parameters to proper variables. However, the CYDOP modification uses this subroutine to transform the basic design parameters into variables used in the lethal area computation. In other words, variables such as fragment fly-off velocity, fragment presented area, fragment density, and fragment spray angle are computed from the five basic warhead and the two fragmentation parameters.

The assigning of new values of parameters to proper variables is controlled by a DO-loop:

```
      DO 100 J=1,ISTP
      IF (JPBK .EQ. 2) I=I+1
      IGO = NAME(I)
      IF(IPRNT5.EQ.1) WRITE(6.500) IGO
  500 FORMAT(1X,6HIGO = ,I3)
      GO TO (10,20,30,40,40,40,40,40,40,40,40,40,40,50,60,70,74,
      75,76,77 1,78,79),IGO
```

The loop is executed ISTP times, where ISTP is equal to 1 or the number of variables optimized or parameterized. The value of ISTP is determined depending on conditions set in the mainline. NAME (I) contains a value

representing a variable that is optimized or parameterized. Depending on this value, the program branches to one of 13 different segments. Statements 10, 20, 30, 50, and 70 deal only with standard variables (namely, HOB, VM, ALPHA, ZONEL, and MINI-mass). If KDGN=1, statements 40 and 60 transfer immediately to statements 73 and 72, respectively. This is done because these sections are not used if the CYDOP segment is executed.

```
 40 CONTINUE
    IF(KDGN.EQ.1) GO TO 73
       .          .         .
       .          .         .
       .          .         .
 60 CONTINUE
    IF(KDGN.EQ.1) GO TO 72
       .          .         .
       .          .         .
       .          .         .
 72 THSU(1) = X(I)
    THSUR(1) = X(I)*CONV
    GO TO 100
 73 FM(1,1) = X(I)
    GO TO 100
```

Statement numbers 74 through 79 assign design parameters to proper variables. Statement 100 is the end of the DO-loop that controls the switching of variables.

```
 74 WVOL = X(I)
    GO TO 100
 75 WWT=X(I)
    GO TO 100
 76 DWH = X(I)
    GO TO 100
 77 RLD = X(I)
    GO TO 100
 78 RCM = X(I)
    GO TO 100
 79 RHW = X(I)
100 CONTINUE
```

The next two statements cause the program to skip the design computation, if it is not applicable.

```
C        SKIP DESIGN COMPUTATION IF NOT APPLICABLE
      IF(KDGN.NE.1) GO TO 110
      IF(JPBK.NE.2.AND.I.NE.1.AND.NPAR.GT.0) GO TO 110
      B = RHOEX
      IF(IPRNT5.EQ.1) WRITE(6,501) NCOMB
  501 FORMAT(1X,*NCOMB =*,I5)
```

B is set equal to RHOEX for ease in reading the equations that follow. If IPRNT5=1, the value of the combination number is printed.

Immediately following the previous statements, the program branches into one of ten segments depending on the combination number. These segments correspond to the combinations described in Table I.

```
C       GO TO SEGMENT DEFINED BY THE COMBINATION NUMBER.
C       IN EACH COMBINATION NUMBER SEGMENT, DETERMINE THE VALUE
C FOR THE TWO UNKNOWN VARIABLES IN TERMS OF3 KNOWN VARIABLES
      GOTO(81,82,83,84,85,86,87,88,89,89),NCOMB
```

Combination number 1 determines the diameter of the warhead and the volume of the warhead in terms of the charge-to-metal ratio, length-to-diameter ratio, and warhead weight:

```
C        COMBINATION 1
   81 WC = WWT/(RCM+1.)
      WE = WC*RCM
      WHL = (((WE/B)+(WC/RHOSTL))*(RLD**2)*4./PI)**ONETRD
      DWH = WHL/RLD
      WVOL = (PI*DWH**2)*WHL/4.
      GO TO 93
```

The weight of the case, the weight of the explosive, and the warhead length are determined as intermediary steps, so they need not be determined in later steps.

Similar statements are used for the remaining combination numbers, solving for the two unknown parameters in terms of the three known variables. If NCOMB is input as 9 or 10, an error code is printed and the run terminated.

```
C        COMBINATION 2
   82 WC = WWT/(RCM+1.)
      WE = WC*RCM
      WVOL = (WE/B)+(WC/RHOSTL)
      WHL = 4.*WVOL/(PI*DWH**2)
      RLD = WHL/DWH
      GO TO 93
C        COMBINATION 3
   83 WHL = RLD*DWH
      WVOL=(DWH**2)*WHL*PI/4.
      WC = B*((RHOSTL*WVOL-WWT)/(RHOSTL-B))
      RCM= (WWT-WC)/WC
      GO TO 92
```

```
C           COMBINATION 4
   84 DWH = (4.*WVOL/(PI*RLD))**ONETRD
      WC = B*((RHOSTL*WVOL-WWT)/(RHOSTL-B))
      RCM= (WWT-WC)/WC
      GO TO 91
C           COMBINATION 5
   85 RLD = 4.*WVOL/(PI*DWH**3)
      WC = B*((RHOSTL*WVOL-WWT)/(RHOSTL-B))
      RCM= (WWT-WC)/WC
      GO TO 91
C           COMBINATION 6
   86 WVOL= PI*RLD*(DWH**3)/4.
      WC = WVOL/((RCM/B)+(1./RHOSTL))
      WWT = WC*(RCM+1.)
      GO TO 91
C           COMBINATION 7
   87 DWH = (4.*WVOL/(PI*RLD))**ONETRD
      WWT = (WVOL/((RCM/B)+(1./RHOSTL)))*(1.+RCM)
      GO TO 90
C           COMBINATION 8
   88 RLD = 4.*WVOL/(PI*DWH**3)
      WWT = (WVOL/((RCM/B)+(1./RHOSTL)))*(1.+RCM)
      GO TO 90
C           COMBINATIONS 9 AND 10
C           THE UNKNOWNS IN COMBINATIONS 9 AND 10 CANNOT BE REPRESENTED
C           INTERMS OF THE KNOWN VARIABLES
   89 WRITE(6,99)
   99 FORMAT(1H1,***TWO DEPENDENT VARIABLES INPUT IN DESIGN MODE***)
      CALL EXIT
```

In some of these combinations, weight of the case, weight of the explosive, and warhead length are not determined as intermediary steps. The following statements are included to compute them when necessary:

```
C           DETERMINE W/H CHARACTERISTIC VALUES CALCULATED IN SOME OF
C         THE ABOVE SEGMENTS BUT NOT CALCULATED IN OTHERS
   90 WC = WWT/(RCM+1.)
   91 WHL= RLD*DWH
   92 WE = WWT-WC
```

The program must now transform these design parameters into variables used in the lethal area computation. The first variable computed is the fragment fly-off velocity. The equation utilizes the Gurney formula with the exponential correction factor derived in Appendix II:

```
C           DETERMINE REMAINING W/H CHARACTERISTICS
   93 GAMMA = 1.0 - .4486*EXP(-1.2345*RLD)
      FV(1,1) = GAMMA*GC*SQRT(RCM/(1.+.5*RCM))
```

The variable D, diameter of the explosive, is computed next.

```
D = SQRT(DWH**2-(4.*WC/(PI*WHL*RHOSTL)))
THCK = (DWH-D)/2.
WF = SQRT(FM(1,1)/(7000.*THCK*RHW*RHOSTL))
HF = WF*RHW
TFRAG = 7000.*WC/FM(1,1)
```

The fragment thickness, width, and height are then determined. TFRAG, the total number of fragments, is determined by dividing the weight of one fragment into the total weight of the case.

Since a new warhead length is computed each time, the correction factor to the height of burst also changes.

```
C   HOB = HOB  +  PRESENT CORRECTION FACTOR  -  OLD CORRECTION FACT
  ZB = ZB + (SALP*WHL/24.) - SALP*WDISF
  WDISF= WHL/24.
```

The height of burst must be adjusted accordingly. This is done by subtracting the old correction factor and adding the new factor to the height of burst. The distance from the center of the warhead to the nose of the warhead, WDISF, must also be corrected. This distance is one-half the warhead length (divided by 12 to change inches to feet).

The fragment presented area is computed by taking one-fourth the surface of the fragment. This is then divided by 144 to convert square inches to square feet.

```
C        FPA IS ONE-FOURTH SURFACE AREA DIVIDED BY 144-- TO CHANGE SQ
C       IN TO SQ FT
      FPA(1,1) = (WF*HF+WF*THCK+HF*THCK)/288.
```

The upper polar zone angle is determined by one of the three methods described earlier. If IZN=1, the upper polar zone angle is optimized or parameterized. If THET=0, the upper polar zone angle is held constant. If neither of the above two combinations exist, the spray angle is computed by Shapiro's formula and defined as the upper polar zone angle.

```
C        THREE OPTIONS TO COMPUTE SPRAY--
C        1) IF UPPER ZONE IS OPTIMIZED (IZN=1) THEN THETA IS DETERMINED
C             BY PRESENT VALUE OF THSUR(UPPER POLAR ZONE IN RADIANS)
      IF(IZN.EQ.1) GO TO 95
C        2) THETA IS INPUT AND HELD CONSTANT (THET .NE.O.)
      IF(THET.NE.0.) GO TO 94
C        3) THETA IS COMPUTED BY SHAPIRO S FORMULA
      THETAA = ATAN(FV(1,1)*WHL/(2.*DV*SQRT(WHL**2+(D/2.)**2)))
   94 IF(THET.NE.0.) THETAA = THET*CONV
```

The next set of statements define the polar zone in terms of the variable used in the lethal area computation. The last statement in this set converts the spray angle to degrees.

```
      THSUR(1) = HFPI + THETAA
      THSU(1) = THSUR(1)/CONV
   95 THSLR(1) = HFPI
      THSL(1) = HFPI/CONV
      IF(IZN.EQ.1) THETAA = THSUR(1)-HFPI
      THETAA = THETAA/CONV
```

After the density of the fragments is determined, the subroutine returns control to the mainline.

```
      DENOM = PI2*(COS(THSLR(1))-COS(THSUR(1)))
      RHO(1,1) = TFRAG/DENOM
  110 RETURN
      END
```

The design mode output is executed in program LETHAR (OVERLAY2). This overlay computes the probability of kill, prints the effective and lethal area table, and prints the PK matrix. The design output is placed immediately after the effective and lethal area table (if the effective and lethal area output is requested). If none of the print indicators are set, the inputs, the design mode outputs, and the summary will be the only items printed.

```
C         PRINT EFFECTIVE AND LETHAL AREA DATA
 1605 WRITE (6,11)
      WRITE (6,12) (PLEVEL(M),XEA(M,I),XLA(M,I),XPK(M,I),M = 1,10)
      WRITE (6,13) PLEVEL(11),XEA(11,I),XLA(11,I),XPK(11,I)
      WRITE (6,14) PLEVEL(12),XEA(12,I),XLA(12,I),XPK(12,I)
      WRITE (6,12) PLEVEL(13),XEA(13,I),XLA(13,I),XPK(13,I)
C         PRINT DESIGN MODE COMPUTATION
 1610 IF(KDGN.EQ.1)
     XWRITE(6,101) NTR   ,WWT,WVOL,RLD,RCM,RHW,FM(1,1),WE,WC,WHL,DWH,
THCK 1,HF,WF,TFRAG,FV(1,1),THETAA
  101 FORMAT(/,4X,*NUM      WWT      WVOL     L/D      C/M      H/W      FM
     1   WE       WC       LWH      DWH      FTK      FHT      FWD    FNUMB
     2   FVEL    ANGL*/4X,I3,2F8.2,3F8.3,3F8.1,2F9.3,3F8.3,2F8.0,F7.1)
```

SECTION IV

TEST CASE

Table III illustrates the input deck for a typical execution of the CYDOP computer program. Five variables were parameterized, and a total of 162 warheads were evaluated against a single target element in 84 seconds of central processor unit time on a CDC 6600 computer.

Table IV illustrates a portion of the output obtained from this test case. This output is optional and is obtained by setting IPR2 equal to 1 on card D. It is strongly recommended that, when using the warhead mode, this output be obtained since it contains information about the warhead that will not be found in the summary. The summary is always output and is illustrated in Table V.

There are several variables in Table IV which have not been encountered previously. Effective area is the amount of area in which there is a PK equal to or greater than the designated PK (Minimal). PK (Mean) is defined as follows:

$$\text{PK (Mean)} = \frac{\dfrac{\iint \text{PK da}}{(\text{EA})}}{\text{Effective Data}}$$

Where EA is the Effective Area. Lethal Area, LA, is

$$\text{LA} = \text{PK(Mean)} \cdot \text{EA}$$

In the final line of the output, there are several other new variables:

a. NUM is the number with 0 indicating the first case.

b. FTK is the fragment thickness.

c. FHT is the fragment height.

d. FWD is the fragment width.

e. FNUMB is the number of fragments.

f. FVEL is the initial velocity of the fragments.

g. ANGL is the upper angular limit of the fragment spray.

Table V contains the summary output for the first 12 cases. Not all of the variables being parameterized are shown in the summary. This deficiency is inconvenient, and the program is being modified to correct the problem.

TABLE III. INPUT DECK FOR TYPICAL EXECUTION OF CYDOP PROGRAM

```
                        Column
         1111111111222222222233333333334444444444555555555566666666667777777777
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
Card
A   |TEST CASE FOR DESIGN MODE
B   |         5
C1  |ALPHA             60.       90.       15.
C2  |FM(1)             15.       30.       15.
C3  |WWT                1.        3.        1.
C4  |C/M               0.3       0.7       0.2
C5  |L/D                1.        3.        1.
D   |2111          2             15.       60.        0.      250.              1
E   |TEST CASE WARHEAD
F   |.061                 8800.    25721.7                 1
G   |                                                          1.
K2  |    1    1
L   |151T55V4W
M   | (BLANK)
N   |        0.        0.        1
```

TABLE IV. TEST CASE FOR DESIGN MODE

TEST CASE WARHEAD TARGET ELEMENT NO. 1

WARHEAD ENTRY ANGLE 60.0 DEGREES

WARHEAD VELOCITY 250.0 FT/SEC

FM 1 15.0

BURST HEIGHT .198 FEET

PK (MINIMAL)	EFFECTIVE AREA (SQ FT)	LETHAL AREA (SQ FT)	PK (MEAN)
1.0	0.00000	0.00000	0.00000000
.9	352.33701	338.09014	.95956465
.8	352.33701	338.09014	.95956465
.7	352.33701	338.09014	.95956465
.6	352.33701	338.09014	.95956465
.5	352.33701	338.09014	.95956465
.4	352.33701	338.09014	.95956465
.3	352.33701	338.09014	.95956465
.2	827.70571	465.05914	.56186533
.1	1499.73661	575.45439	.38370364
.005	2429.06160	662.59808	.27277945
.0001	2429.06160	662.59808	.27277945
0.0	55115.62613	662.59808	.01202196

NUM	WWT	WVOL	L/D	C/M	M/W	FM	WE
0	1.00	6.50	1.000	.300	1.000	15.0	.2

WC	LWH	DWH	FTK	FMT	FWD	FNUMB	FVEL	ANGL
.8	2.023	2.023	.240	.178	.178	359.	3908.	4.1

TABLE V. TEST CASE FOR DESIGN MODE

SUMMARY

TARGET NO. 1 TARGET 55 V4 WOOD

TRIAL NO.	TARGET NO.	ALPHA (DEG)	HOB (FT)	W/H VEL. (FPS)	FM(1) GRAINS	LETHAL AREA SQ.FT.
0	1	60.0	.2	250.0	15.0	653.
1	1	75.0	.2	250.0	15.0	1464.
2	1	90.0	.2	250.0	15.0	0.
3	1	60.0	.2	250.0	30.0	602.
4	1	75.0	.2	250.0	30.0	1350.
5	1	90.0	.2	250.0	30.0	0.
6	1	60.0	.2	250.0	15.0	940.
7	1	75.0	.2	250.0	15.0	2011.
8	1	90.0	.2	250.0	15.0	0.
9	1	60.0	.2	250.0	30.0	862.
10	1	75.0	.2	250.0	30.0	1900.
11	1	90.0	.2	250.0	30.0	0.

However, by simply referring to Card C of the input deck, the values of the variables being parameterized can be determined for any of the cases. The rule is that the variable input on the first of the Type C cards will change most quickly while the variable input on the last of the Type C cards will change most slowly. In this test case, therefore, ALPHA varies most quickly and L/D changes most slowly.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

a. The Weapon Optimization Techniques program has been modified so that it is possible to optimize or parameterize basic design parameters for cylindrical warheads.

b. The methodology for fragment fly-off velocity has been investigated, and a correction-factor equation to the Gurney formula has been introduced.

2. RECOMMENDATIONS

a. The possibility of considering blast effects when using this program to optimize design should be investigated.

b. A design option to this program for alternative warhead shapes should be considered as a possible future modification.

c. The possibility of expanding the warhead/target representation to consider more than just point locations should be investigated.

d. Future programming efforts should be thoroughly documented to eliminate any uncertainty as to how the program accomplishes its computations.

REFERENCES

1. Weapon Optimization Techniques. AFATL-TR-67-128, Air Force Armament Laboratory, Eglin Air Force Base, Florida, October 1967. Unclassified. AD832,700.

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4. Gurney, R. W. The Initial Velocities of Fragments from Bombs, Shells, and Grenades. Ballistic Research Laboratory Report No. 405, September 1943.

5. Elements of Terminal Ballistics, Part One, Introduction, Kill Mechanisms, and Vulnerability. Engineering Design Handbook, Army Materiel Command Pamphlet 706-160, November 1962.

6. Terminal Blastic Effects. Naval Weapons Laboratory Report No. 1821.

7. Warheads--General. Engineering Design Handbook, Ordnance Corps Pamphlet ORDP-20-290, July 1959.

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APPENDIX I

UTILIZATION REPORT

SECTION I CONSTANTS SECTION

CARD A

COLUMN	ITEM	SCALING
1-72	GTITLE = GENERAL TITLE	12A6

CARD B

COLUMN	ITEM	SCALING
1-5	NVOPT = NUMBER OF VARIABLES TO BE OPTIMIZED(MAX OF 15)	I5
6-10	NPAR = NUMBER OF VARIABLES TO BE PARAMETERIZED(MAX OF 8) IF NVOPT IS GREATER THAN 0, NPAR = 0 AND VICE-VERSA.	I5
11-20	CC1	F10.0
21-30	CC2 OPTIMIZATION PROCEDURE WILL NOT CONVERGE UNTIL THE FOLLOWING TWO CONDITIONS ARE SATISFIED. AL(I) IS LETHAL AREA OF TRIAL I. 1. ABSOLUTE VALUE OF((AL(N-1)-AL(N-2))/AL(N-2)) MUST BE LESS THAN CC1 AND 2. ABSOLUTE VALUE OF((AL(N)-AL(N-1))/AL(N-1)) MUST BE LESS THAN CC2.	F10.0
35	IPR6 = 1, PRINTS INTERMEDIATE VALUES IN OPTIMIZATION PORTION OF PROGRAM.	I1
40	IOPPAT= 1, OPTIMIZES PATTERN SIZE.	I1
45	IEACH = 1, IN PARAMETRIC MODE,INDICATES PATTERN SIZE WILL BE OPTIMIZED FOR EACH SET OF CONDITIONS. 0, PATTERN SIZE WILL BE OPTIMIZED FOR THE LARGEST VALUE OF $\prod_{1}^{N} (AL)$ WHERE N IS THE NO. OF TARGET ELEMENTS.	I1
46	LAPAR = 1, LETHAL AREA WILL BE PARAMETERIZED	I1

NOTE. IF LAPAR = 1, SKIP TO CARD W1.

CARD C

COLUMN	ITEM	SCALING
1-6	NAME(I) = NAME OF VARIABLE TO BE OPTIMIZED OR PARAMETERIZED FROM VARIABLE TABLE	A6
7-10	BLANK	4X
11-20	XMN(I) = VARIABLE MINIMUM	F10.0
21-30	XMX(I) = VARIABLE MAXIMUM	F10.0
31-40	X(I) = FIRST ESTIMATE IN OPTIMIZATION MODE = DELTA X IN PARAMETRIC MODE	F10.0

CARD C IS REPEATED FOR EACH VARIABLE BEING OPTIMIZED OR PARAMETERIZED

VARIABLE TABLE

COLUMN	ITEM	DIMENSION
1-3	HOB = WARHEAD HEIGHT OF BURST	FT.
1-3	VM = TERMINAL WARHEAD VELOCITY	FT./SEC.
1-3	ALPHA = TERMINAL WARHEAD ATTACK ANGLE	DEGREES
1-5	FM(I) = FRAGMENT MASS, GROUP I (MAX OF 10 GROUPS)	GRAINS
1-5	ZONEL = LOWER LIMIT OF FIRST ZONE IN WARHEAD	DEGREES
1-5	ZONEU = UPPER LIMIT OF LAST ZONE IN WARHEAD	DEGREES
1-3	FM1 = FRAGMENT MASS FOR PLANE OF FRAGMENTS	GRAINS
1-3 *	VOL = VOLUME OF WARHEAD	CU. IN.
1-3 *	WWT = WEIGHT OF WARHEAD	LBS
1-3 *	DWH = DIAMETER OF WARHEAD	IN.
1-3 *	L/D = RATIO OF LENGTH TO DIAMETER	-
1-3 *	C/M = RATIO OF WEIGHT OF CHARGE TO WEIGHT OF METAL	-
1-3 *	H/W = RATIO OF HEIGHT TO WIDTH OF FRAGMENTS	-

NAMES MUST BEGIN IN COLUMN 1 AND BE IN THE EXACT FORMAT AS INDICATED IN THIS TABLE

* USE WITH DESIGN MODE ONLY (KDGN = 1). DESIGN MODE CAN ALSO USE HOB, VM, ALPHA, FM(1), AND ZONEU. REFER TO NOTE AT THE BOTTOM OF THE FIRST PAGE OF SECTION IIC BEFORE CHOOSING ANY OF THE DESIGN PARAMETERS.

CARD D

COLUMN	ITEM	SCALING
1	IPRNT1 = 1, PRINTS STATIC, DYNAMIC AND FRAGMENTATION WARHEAD DATA	I1
2	IPRNT2 = 1, PRINTS EFFECTIVE AND LETHAL AREA DATA	I1
3	IPRNT3 = 1, PRINTS PK MATRIX	I1
4	IPRNT4 = 1, PRINTS TARGET DATA INPUT	I1
5	IPRNT5 = 1, SPECIAL PRINT USED FOR PROGRAM CHECKOUT	I1
	SET THE INDICATOR TO 0 TO OMIT THE SPECIFIED PRINTOUT	
15	INDXR = 1, INDICATES EVERY RADIUS IN THE TABLE OF RADII FOR THE TARGET DAMAGE ASSESSMENT GRID IS TO BE USED = 2, INDICATES EVERY OTHER RADIUS = 3, INDICATES EVERY THIRD RADIUS ETC	I5
21-30	DGRID = ANGULAR INCREMENT FOR TARGET DAMAGE ASSESSMENT GRID. SHOULD DIVIDE INTO 180 EVENLY (DEGREES)	F10.0
31-40	ALPHA = WARHEAD TERMINAL ATTACK ANGLE (DEGREES)	F10.0
41-50	HOB= WARHEAD HEIGHT OF BURST (FT)	F10.0
51-60	VM = WARHEAD TERMINAL VELOCITY (FT/SEC)	F10.0
61-65	RGMAX = MAXIMUM EFFECTIVE RADIUS TO BE EVALUATED. IF RGMAX=0, GRID RADIUS WILL BE DETERMINED BY A CALCULATED EFFECTIVE RANGE OF WARHEAD.	F5.0
66-70	WDIS = DISTANCE FROM THE NOSE OF THE MISSILE TO THE CENTER OF THE WH SECTION(INCHES)	F5.0
75	KDGN = 1, DESIGN MODE FLAG. USE SECTION II C IF KDGN=1.	I5

SECTION II WARHEAD SECTION

NOTE- USE TABLE IIA,IIB,OR IIC AS APPROPRIATE

SECTION IIA

(WARHEADS WITH CONSTANT CHARGE TO MASS RATIO)

CARD E

COLUMN	ITEM	SCALING
1	ITAPE = 1, INDICATES CERTAIN VARIABLES WILL BE READ FROM TAPE	I1
2-3	ISKP = NO. OF THE FILE TO BE READ FROM TAPE.	I2
4-9	TITLE = ABBREVIATED NAME OF THE FILE TO BE READ FROM TAPE.	A6

CARD F - OMIT WHEN ITAPE=1

COLUMN	ITEM	SCALING
1-72	WTITLE = WARHEAD TITLE	12A6

CARD G - WHEN ITAPE=1, INPUT COLUMNS 11-35 ONLY

COLUMN	ITEM	SCALING
1-5	BLANK	I5
6-10	NPOLAR = NUMBER OF POLAR ZONES REQUIRED TO DESCRIBE THE FRAGMENTATION DATA FOR WARHEAD (DEG) (MAX OF 36)	I5
	NOTE. IF WH CONTAINS ONLY A PLANE OF FRAGMENTS AND NO FRAGMENTS IN POLAR ZONES, THEN NPOLAR MAY BE SET TO 0 AND CARDS H AND I OMITTED.	
11-20	PBEXP = THE BARE CHARGE OF TNT EQUIVALENT EXPLOSIVE IN THE WARHEAD (LBS)	F10.0
21-30	RHOMTL = DENSITY OF FRAGMENT MATERIAL (LBS/IN**3) (NOT USED IF FRAGMENT IS STEEL)	F10.0
35	MINI = 1, INDICATES WH CONTAINS A PLANE OF FRAGMENTS.	I5
36-60	BLANK	
61-70	FACTK = K FACTOR, (FT**2/GR**2/3)	F10.0
71	IFRAG FRAGMENT DENSITY INDICATOR = 0 THE FRAGMENT DENSITY, RHO(I,J), IS INPUT IN FRAGMENTS/STERADIAN = 1 THE FRAGMENT DENSITY IS INPUT AS THE TOTAL NUMBER OF FRAGMENTS AND THE PROGRAM COMPUTES FRAGMENTS/ STERADIAN	I1
72	INDCD = FRAGMENT DRAG INDICATOR, 1 = SPHERE, 2 = CUBE, 3 = RANDOM. IF INDCD GT 3, A SPECIAL DRAG CURVE MUST BE INPUT USING CARDS J1.	I1

CARD H - OMIT WHEN ITAPE=1.

COLUMN	ITEM	SCALING
1-5	NGPS(J) = NUMBER OF CLASSES OF FRAGMENTATION DATA IN POLAR ZONE J. ALL ZONES MUST HAVE SAME NUMBER OF CLASSES. (MAX OF 10)	I5
6-10	BLANK	I5
11-20	THSU(J) = UPPER ANGLE DEFINING POLAR ZONE J FOR WARHEAD (DEG)	F10.0
21-30	THSL(J) = LOWER ANGLE DEFINING POLAR ZONE J FOR WARHEAD (DEG)	F10.0

CARD I - OMIT WHEN ITAPE=1.

COLUMN	ITEM	SCALING
1-10	FM(J,K) = FRAGMENT MASS FOR POLAR ZONE J, AND CLASS K (GRAIN)	F10.0
11-20	FV(J,K) = INITIAL VELOCITY FOR POLAR ZONE J AND CLASS K (FT/SEC)	F10.0
21-30	FPA(J,K)= FRAGMENT PRESENTED AREA FOR POLAR ZONE J AND CLASS K (SQ. IN.)	F10.0
31-40	BLANK	F10.0
41-50	RHO(J,K)= FRAGMENT DENSITY OR NUMBER OF FRAGMENTS	F10.0
51-60	D1(K) = WIDTH OF RECTANGULAR FRAGMENTS IN CLASS K (IN)	F10.0
61-70	D2(K) = HEIGHT OF RECTANGULAR FRAGMENTS IN CLASS K(IN)	F10.0

D1(K) AND D2(K) ARE REQUIRED ONLY IF FRAGMENT MASS IS BEING OPTIMIZED OR PARAMETERIZED

CARD I IS REPEATED NGPS(I) TIMES.

CARDS H AND I ARE REPEATED FOR EACH POLAR ZONE

CARD I1 (OMIT IF MINI .NE. 1)

COLUMN	ITEM	SCALING
1-10	FM1 = FRAGMENT MASS FOR MINI PLANE OF FRAGMENTS. (GRAINS)	F10.0
11-20	FV1 = INITIAL VELOCITY FOR MINI PLANE OF FRAGMENTS. (FT/SEC)	F10.0
21-30	FPA1 = FRAGMENT PRESENTED AREA FOR MINI PLANE OF FRAGMENTS. (SQ. IN.)	F10.0
31-40	BLANK	
41-50	RHO1 = NO. OF FRAGMENTS IN MINI PLANE OF FRAGMENTS.	F10.0
51-60	DD1 = WIDTH OF RECTANGULAR FRAGMENTS IN MINI PLANE OF FRAGMENTS. (IN.)	F10.0
61-70	DD2 = HEIGHT OF RECTANGULAR FRAGMENTS IN MINI PLANE OF FRAGMENTS. (IN.)	F10.0

IF INDCD IS LESS THAN 3, OMIT CARDS J1 (SPECIAL DRAG TABLE)

CARD J1

COLUMN	ITEM	SCALING
	ENABLES INPUT OF FLECHETTE DRAG COEFFICIENTS	
1-10	CD(I) = DRAG COEFFICIENT AT VELOCITY = 0 FT/SEC	F10.0
11-20	CD(I) = DRAG COEFFICIENT AT VELOCITY = 447 FT/SEC	F10.0
.	.	
.	.	
.	.	
61-70	CD(7) = DRAG COEFFICIENT AT VELOCITY = 1005 FT/SEC	F10.0

CARD J1 IS REPEATED UNTIL 25 DRAG COEFFICIENTS HAVE BEEN INPUT(7 PER CARD). CORRESPONDING VELOCITIES MUST BE 0,447,558,670,782,893,1005,1116,1228,1340, 1451,1563,1786,1898,2010,2233,2679,3014,3350,3908, 4679,5024,5582,6475,10048.

SECTION IIB

(WARHEADS WITH VARYING CHARGE TO MASS RATIO - OPTIMIZATION OR PARAMETERIC RUNS FOR SPHERICAL FRAGMENT MASS ONLY)

CARD E

FORMAT

COLUMN	ITEM	SCALING
1-72	WTITLE = WARHEAD TITLE	12A6

CARD F

FORMAT

COLUMN	ITEM	SCALING
5	IWHDT = WARHEAD TYPE, 1 = SPHERE OR TABULAR DATA, 2 = CYLINDER	I1
6-10	NPOLAR = NUMBER OF POLAR ZONES REQUIRED TO DESCRIBE FRAGMENTATION DATA FOR WARHEAD (MAX 36)	I5
11-20	PBEXP = BARE CHARGE OF TNT EQUIVALENT EXPLOSIVE IN THE WARHEAD (LBS)	F10.0
21-30	RHOMTL = DENSITY OF FRAGMENT MATERIAL. BLANK IF USING STEEL (LBS./CU. IN.)	F10.0
35	MINI = 1, INDICATES WH CONTAINS A PLANE OF FRAGMENTS.	I1
41-50	WLGTH = LENGTH OF WARHEAD (INCHES)	F10.0
51-60	WDIAM = DIAMETER OF WARHEAD (INCHES)	F10.0
61-70	FACTK = K FACTOR (FT**2/GR**2/3)	F10.0
71	IFRAG = FRAGMENT DENSITY INDICATOR =0, THE FRAGMENT DENSITY, RHO(I,J) IS INPUT IN FRAGMENTS/STERADIAN. IF IFRAG = 1, FRAGMENT DENSITY IS INPUT AS THE TOTAL NUMBER OF FRAGMENTS AND FRAGMENT/STERADIAN IS COMPUTED.	I1
72	INDCD = DRAG INDICATOR, 1 = SPHERE, 2 = CUBE, 3 = RANDOM. IF INDCD GT 3, SPECIAL DRAG CURVE MUST BE INPUT USING CARDS I1	I1

NOTE - IF IRAD = 1, PBEXP NOT REQUIRED

NOTE - LEAVE FACTK BLANK IF FRAGMENT PRESENTED AREA IS USED

CARD G

CARD G IS REPEATED NPOLAR TIMES

COLUMN	ITEM	SCALING
1-5	NGPS(I) = NUMBER OF CLASSES OF FRAGMENTATION DATA IN POLAR ZONE I. ALL ZONES MUST HAVE SAME NUMBER OF CLASSES. MAX OF 10	I5
6-10	BLANK	
11-20	THSU(I) = UPPER ANGLE DEFINING POLAR ZONE 1 FOR WARHEAD. MAX OF 180(DEGREES)	F10.0
21-30	THSU(I) = LOWER ANGLE DEFINING POLAR ZONE FOR WARHEAD MAX OF 180(DEGREES)	F10.0

CARD H1

COLUMN	ITEM	SCALING
5	IFORM = 0, TABULAR WARHEAD DATA, 1 = GURNEY FORMULA	I1
6-10	NMAS = NUMBER OF MASSES IN TABLE MAX OF 14, NOT REQUIRED IF IFORM = 1	I5
11-20	ENERGY = ENERGY CONSTANT, NOT REQUIRED IF IFORM = 0	F10.0
21-30	PACKEF = PACKING EFFICIENCY EP ,NOT USED IF IFORM=0	F10.0
31-40	RHOMTX = DENSITY OF MATRIX MATERIAL (LBS/IN**3) NOT REQUIRED IF IFORM = 0	F10.0
41-50	RHOEXP = DENSITY OF EXPLOSIVE, NOT REQUIRED IF IFORM = 0	F10.0

CARDS H2-H4 NOT REQUIRED IF IFORM = 1

CARD H2

COLUMN	ITEM	SCALING
1-10	SFMAS(I) = FIRST MASS IN TABLE(GRAINS)	F10.0

CARD H3

COLUMN	ITEM	SCALING
1-10	SVEL(I) = SPHERICAL FRAGMENT VELOCITY IN CLASS I (FT/SEC) MAX OF SEVEN CLASSES	F10.0

CARD H4

1-10	SRNO(I) = NUMBER OF SPHERICAL FRAGMENTS IN FIRST CLASS MAX OF SEVEN CLASSES	F10.0

REPEAT CARDS H3 AND H4 FOR EACH POLAR ZONE
REPEAT CARDS H2 THROUGH H4 NMAS TIMES

IFINDCD IS LESS THAN 3, OMIT CARDS I1 (SPECIAL DRAG TABLE)

CARD I1 (SAME AS CARDJ2 IN SECTION IIA)

SECTION IIC

(KDGN=1, FOR DESIGN MODE)

CARD E

COLUMN	ITEM	SCALING
1-72	WTITLE = WARHEAD TITLE	12A6

CARD F

COLUMN		ITEM	SCALING
1-10	RHOEX	= DENSITY OF EXPLOSIVE (LBS./CU. IN.)	F10.0
11-20	RHOSTL	= DENSITY OF METAL (LBS./CU. IN.) LEAVE BLANK IF METAL IS STEEL	F10.0
21-30	GC	= GURNEY CONSTANT (FT./SEC.)	F10.0
31-40	DV	= DETONATION VELOCITY (FT./SEC.)	F10.0
41-50	THET	= SPRAY ANGLE (DEG.)	F10.0
		= BLANK, IF NOT HELD CONSTANT	F10.0
55	NCOMB	= COMBINATION NUMBER	I5

NCOMB TABLE

(NCOMB IS THE FLAG USED TO DETERMINE WHICH SET OF DESIGN PARAMETERS IS TO BE OPTIMIZED OR PARAMETERIZED)

NCOMB		--------PARAMETERS--------				
1		WWT	C/M	L/D	H/W	FM(1)
2		WWT	C/M	DWH	H/W	FM(1)
3		WWT	L/D	DWH	H/W	FM(1)
4		WWT	L/D	VOL	H/W	FM(1)
5		WWT	DWH	VOL	H/W	FM(1)
6		C/M	L/D	DWH	H/W	FM(1)
7		C/M	L/D	VOL	H/W	FM(1)
8		C/M	DWH	VOL	H/W	FM(1)
9	*	VOL	WWT	C/M	H/W	FM(1)
10	*	VOL	DWH	L/D	H/W	FM(1)

NOTE--1) IN USING THE DESIGN MODE THE USER MUST ACCOMPLISH THE FOLLOWING

A. SELECT A COMBINATION NUMBER (NCOMB TABLE) BASED ON WARHEAD CONSTRAINTS.

B. OPTIMIZE OR PARAMETERIZE ANY VARIABLE IN THE CHOSEN COMBINATION BY USE OF CARD C. HOB, VM, ALPHA, AND ZONEU CAN ALSO BE OPTIMIZED OR PARAMETERIZED.

C. ANY VARIABLE IN THE CHOSEN COMBINATION THAT IS NOT OPTIMIZED OR PARAMETERIZED MUST HAVE A CONSTANT VALUE ENTERED ON CARD G.

2)*COMBINATION NUMBERS 9 AND 10 HAVE NO UNIQUE SOLUTION FOR THE TWO UNKNOWNS, AND SO CANNOT BE USED. THEY ARE LISTED HERE FOR COMPLETION ONLY.

CARD G
(INPUT VALUES ONLY FOR THE VARIABLES TO BE HELD CONSTANT)

COLUMN	ITEM	SCALING
1-10	WVOL = WARHEAD VOLUME (CU. IN.)	F10.0
11-20	WWT = WARHEAD WEIGHT (LBS.)	F10.0
21-30	DWH = DIAMETER OF WARHEAD(IN.)	F10.0
31-40	RLD = RATIO OF LENGTH TO DIAMETER OF WARHEAD	F10.0
41-50	RCM = RATIO OF CHARGE TO METAL OF WARHEAD	F10.0
51-60	RHW = RATIO OF HEIGHT TO WIDTH OF FRAGMENTS	F10.0
61-70	FM(1,1) = FRAGMENT MASS (GRAINS)	F10.0

NOTE- IF A VARIABLE MUST BE HELD CONSTANT IN A GIVEN RUN, THAT VARIABLE MUST APPEAR IN THE LIST CORRESPONDING TO THE COMBINATION NUMBER INPUT.

SECTION III TARGET SECTION

CARD K2

COLUMN	ITEM	SCALING
5	NELMTS = NUMBER OF TARGET ELEMENTS (MAX OF 5)	I5
6-10	NESH = NUMBER OF MATERIAL TARGET ELEMENTS WHICH ARE SAME HEIGHT. THESE SHOULD BE GROUPED TOGETHER AS THE FIRST TARGETS TO BE INPUT. THOSE ON TAPE SHOULD BE ARRANGED IN ASCENDING ORDER OF FILE NUMBER.	I5
15-35	LTYPE(I) FOR I=1,...,5 = 0 FOR MATERIEL, = 1 FOR PERSONNEL	5I5

CARD L

COLUMN	ITEM	SCALING
1	ITAPE = 1, INDICATES CERTAIN VARIABLES WILL BE READ FROM TAPE. = 0, NO VARIABLES READ FROM TAPE	I1
2-3	ISKPP = FILE NUMBER TO BE READ FROM TAPE	I2
4-9	TITLE = ABBREVIATED NAME OF FILE TO BE READ FROM TAPE.	A6

CARD M - OMIT WHEN ITAPE=1.

COLUMN	ITEM	SCALING
1-72	ETITLE = ELEMENT TITLE	12A6

NOTE. IF THE TARGET IS PERSONNEL, SKIP TO CARD U

CARD N - OMIT COL 1-40 WHEN ITAPE=1.

COLUMN	ITEM	SCALING
1-5	BLANK	
6-10	NFMS(I) = NUMBER OF FRAGMENT MASSES USED TO DESCRIBE THE VULNERABILITY OF TARGET ELEMENT I (MAX OF 10)	I5
11-15	NVEL(I) = NUMBER OF FRAGMENT VELOCITIES USED TO DESCRIBE THE VULNERABILITY OF TARGET ELEMENT I (MAX OF 12)	I5
16-20	NELVS(I) = NUMBER OF ELEVATION ANGLES USED TO DESCRIBE THE VULNERABILITY OF TARGET ELEMENT I (MAX OF 7)	I5
25	IKT(I)= 0, THE TARGET VULNERABILITY DATA AS A FUNCTION OF ELEVATION ANGLE IS USED. 1, THE TARGET VULNERABILITY DATA FOR THE UPPER HEMISPHERE IS USED. 2, THIS OPTION INCORPORATED INTO THE PROGRAM TO EVALUATE VULNERABILITY FOR FUTURE ELEMENTS. NOT NEEDED AT THIS TIME.	I2
31-40	ZT(I) = HEIGHT OF TARGET ELEMENT CENTROID.	F10.0
41-50	TLGTH(I)= LENGTH OF ELEMENT(I).	F10.0
51-60	TWDTH(I)=WIDTH OF ELEMENT(I).	F10.0
61-70	THGT(I) = HEIGHT OF ELEMENT(I).	F10.0

CARD O

COLUMN	ITEM	SCALING
1-10	BLSTL1(I) = EITHER THE IMPULSE LEVEL OR THE BLAST RADIUS FOR PKB = 1.0 OF ELEMENT I.	F10.0
11-20	BLSTL2(I) = EITHER THE IMPULSE LEVEL OR THE BLAST RADIUS AT WHICH PKB BECOMES EQUAL TO 0.	F10.0
30	IRAD(I) = 0 INDICATES BLAST LEVEL IS USED = 1 INDICATES BLAST RADII ARE USED	I1

CARD P - OMIT TYPES P THROUGH T WHEN ITAPE = 1

COLUMN	ITEM	SCALING
1-70	AV(IT,JT,KT) = VULNERABLE AREA FOR FRAGMENT MASS IT, FRAGMENT VELOCITY JT AND FRAGMENT STRIKING ANGLE KT (KT = 1,NELVS)	14F5.0

CARD Q

COLUMN	ITEM	SCALING
1-40	FMAS(I,ITT) = AN ASCENDING ORDERED TABLE OF FRAGMENT MASSES USED IN THE VULNERABILITY DATA FOR ELEMENT I. (ITT = 1,NFMS)	8F5.0

CARD R

COLUMN	ITEM	SCALING
1-70	VEL(I,JTT) = VELOCITY (JTT= 1,NVEL)	14F5.0

CARD S

COLUMN	ITEM	SCALING
1-30	ELV(I,KTT) = AN ASCENDING ORDERED TABLE OF FRAGMENT STRIKING ANGLES USED IN THE VULNERABILITY PATH FOR ELEMENT I (KTT = 1,NELVS)	6F5.0

CARD T

COLUMN	ITEM	SCALING
1-30	VEETBL(I,ITT,KTT) = MINIMUM LETHAL FRAGMENT VELOCITY FOR TARGET ELEMENT I, FRAGMENT ZONE N, FRAGMENT CLASS M-(M=1,NGRS)	6F5.0

CARD P IS REPEATED (NFMS(I) X NVEL(I)) TIMES.
CARD T IS REPEATED NFMS(I) TIMES
CARDS L THROUGH T ARE REPEATED FOR EACH MATERIEL TARGET

IF TARGET IS PERSONNEL, OMIT CARDS N THROUGH T AND USE THE FOLLOWING CARDS IN THEIR PLACE

CARD U

COLUMN	ITEM	SCALING
1-5	ITROOP(I) = 1 FOR PRONE TROOPS = 2 FOR STANDING TROOPS, 3 = FOXHOLE	I5
6-10	BLANK	
11-20	ZT(I) = HEIGHT OF TARGET (FT)	F10.0
21-30	BLSTL1(I) = EITHER THE IMPULSE LEVEL OR THE BLAST RADIUS FOR PKB = 1.0 OF ELEMENT I.	F10.0
31-40	BLSTL2(I) = EITHER THE IMPULSE LEVEL OR THE BLAST RADIUS AT WHICH PKB BECOMES EQUAL TO 0.	F10.0
45	IRAD(I) = 0 INDICATES BLAST LEVEL IS USED = 1 INDICATES BLAST RADII ARE USED	I1

CARD V - OMIT WHEN ITAPE = 1.

COLUMN	ITEM	SCALING
1-10	A = CONSTANT DEFINING CASUALTY CRITERION	F10.0
11-20	B = CONSTANT DEFINING CASUALTY CRITERION	F10.0
21-30	C = CONSTANT DEFINING CASUALTY CRITERION	F10.0

REPEAT CARDS M,U, AND V FOR EACH PERSONNEL TARGET

CARD W1 OMIT TYPES W1 THROUGH Z IF IOPPAT=0

COLUMN	ITEM	SCALING
1	NLPAR = NUMBER OF VARIABLES TO BE PARAMETERIZED IN THE PATTERN OPTIMIZATION SECTION.	I1

CARD W2 REPEAT NLPAR TIMES. OMIT IF IOPPAT = 0

COLUMN	ITEM	SCALING
1-6	NAMES(M) = NAME OF VARIABLE TO BE PARAMETERIZED.	A6
11-20	XMNL(M) = VARIABLE MINIMUM	F10.0
21-30	XMXL(M) = VARIABLE MAXIMUM	F10.0
31-40	XL(M) = DELTA X	F10.0

PATTERN OPTIMIZATION VARIABLE TABLE

COLUMN	ITEM
1-5	NBLTS = NUMBER OF BOMBLETS
1-5	TARHL = TARGET HALF LENGTH.
1-5	TARHW = TARGET HALF WIDTH.
1-4	SIGW = STANDARD DEVIATION OF DELIVERY ERROR IN THE RANGE DIRECTION.
1-4	SIGL = STANDARD DEVIATION OF DELIVERY ERROR IN THE DEFLECTION DIRECTION.
1-5	AREAL = LETHAL AREA. IF THIS VARIABLE IS PARAMETERIZED LAPAR MUST BE 1.

CARD X   OMIT IF IOPPAT = 0

COLUMN	ITEM	SCALING
1-10	TARHL = TARGET HALF LENGTH.	F10.0
11-20	TARHW = TARGET HALF WIDTH.	F10.0
25	IDTAR = 0, INDICATES ELLIPTICAL TARGET SHAPE 1, INDICATES RECTANGULAR TARGET SHAPE	I1

CARD Y   OMIT IF IOPPAT = 0

COLUMN	ITEM	SCALING
1-10	PATHL = WEAPON PATTERN HALF LENGTH.	F10.0
11-20	PATHW = WEAPON PATTERN HALF WIDTH.	F10.0
25	IDPAT = 0, INDICATES ELLIPTICAL PATTERN SHAPE. 1, INDICATES RECTANGULAR PATTERN SHAPE.	I1
31-40	SIGL = STANDARD DEVIATION OF DELIVERY ERROR IN THE RANGE DIRECTION.	F10.0
41-50	SIGW = STANDARD DEVIATION OF DELIVERY ERROR IN THE DEFLECTION DIRECTION.	F10.0
51-60	DL = DELTA ON PATTERN SIZE	F10.0
61-70	NBLTS = NO. OF BOMBLETS.	I10

CARD Z

COLUMN	ITEM	SCALING
1-10	FP(1) = WEIGHTING FACTOR FOR TARGET ELEMENT I.	F10.0
11-20	FP(2)	
.		
.		
41-50	FP(5)	

NOTE. SUM OF THE ABOVE MUST BE 1.

NOTE. RUNS MAY BE STACKED BY PLACING A *RUN CARD
(* IN COL. 1, RUN IN COLS. 7-9) AFTER LAST DATA
CARD AND THEN REPEATING THE CARDS IN TABLE I.
THE GTITLE CARD IS USED TO INDICATE IF THE WH
DATA AND/OR THE TARGET DATA ARE TO BE CHANGED.
IF NEW WARHEAD DATA IS IN GTITLE CARD COLS. 1-16,
THEN TABLE IIA OR IIB CARDS MUST BE INPUT.
IF NEW TARGET DATA IS IN COLS. 20-34, THEN THE
ENTIRE TABLE III CARD DECK MUST BE INPUT. COLS. 35-72
MAY CONTAIN ANY OTHER INFORMATION TO BE PRINTED AT
TOP OF PAGE.
THIS MAY BE DONE ANY NUMBER OF TIMES, THUS ENABLING
THE USER TO OPTIMIZE SEVERAL WARHEADS AGAINST VARIOUS
TARGETS.

SPECIAL INPUT SECTION USED TO STORE DATA ON TAPE

CARD 1

COLUMN		ITEM	SCALING
1-6	WT	= ABBREVIATED NAME OF THE FILE TO BE READ FROM TAPE.	A6

CARD 2

COLUMN		ITEM	SCALING
1-72	WTITLE	= WARHEAD TITLE	12A6

CARD 3

COLUMN		ITEM	SCALING
1-10	NPOLAR	= SAME AS CARD H BUT READ FROM TAPE.	I5
61-70	FACTK	= SAME AS CARD H BUT READ FROM TAPE.	F10.0
71	IFRAG	= SAME AS CARD H BUT READ FROM TAPE.	F10.0
72	INDCD	= SAME AS CARD H BUT READ FROM TAPE.	F10.0

CARD 4

COLUMN		ITEM	SCALING
1-5	NGPS(J)	= NUMBER OF CLASSES OF FRAGMENTATION DATA IN POLAR ZONE J. ALL ZONES MUST HAVE SAME NUMBER OF CLASSES.	I5
6-10	BLANK		
11-20	THSU(J)	= UPPER ANGLE DEFINING POLAR ZONE J FOR WARHEAD (DEG)	F10.0
21-30	THSL(J)	= LOWER ANGLE DEFINING POLAR ZONE J FOR WARHEAD (DEG)	F10.0

CARD 5

COLUMN	SYMBOL	ITEM	SCALING
1-10	FM(J,K)	= SAME AS CARD M BUT READ FROM TAPE.	F10.0
11-20	FV(J,K)	= SAME AS CARD M BUT READ FROM TAPE.	F10.0
21-30	ADUM	= BLANKS	F10.0
31-40	XDUM	= BLANKS	F10.0
41-50	RHO(J,K)	= SAME AS CARD M BUT READ FROM TAPE.	F10.0
51-60	BDUM	= BLANKS	F10.0
61-70	CDUM	= BLANKS	F10.0

CARD 6

COLUMN		ITEM	SCALING
1-6	TARGTI	= ABBREVIATED NAME OF FILE TO BE READ FROM TAPE.	A6

CARD 7

COLUMN	SYMBOL	ITEM	SCALING
1-72	ETITLE = ELEMENT TITLE		12A6

CARD 8

COLUMN	SYMBOL	ITEM	SCALING
1-5	BLANK		
6-10	NFMS(I) = NUMBER OF FRAGMENT MASSES USED TO DESCRIBE THE VULNERABILITY OF TARGET ELEMENT I. (MAX OF 10)		I5
11-15	NVEL(I) = NUMBER OF FRAGMENT VELOCITIES USED TO DESCRIBE THE VULNERABILITY OF TARGET ELEMENT I (MAX OF 21)		I5
16-20	NELVS(I) = NUMBER OF ELEVATION ANGLES USED TO DESCRIBE THE VULNERABILITY OF TARGET ELEMENT I (MAX OF 10)		I5
25	IKT(I) = 0, THE TARGET VULNERABILITY DATA AS A FUNCTION OF ELVS ELEVATION ANGLE ARE USED. = 1, THE TARGET VULNERABILITY DATA FOR THE UPPER HEMISPHERE ARE USED.		I1
31-40	ZT(I) = HEIGHT OF TARGET ELEMENT CENTROID (FT)		F10.0

CARD 9

COLUMN	SYMBOL	ITEM	SCALING
1-70	AV(IT,JT,KT) = VULNERABLE AREA FOR FRAGMENT MASS IT, FRAGMENT VELOCITY JT AND FRAGMENT STRIKING ANGLE KT (KT = 1,NELVS)		14F5.0

CARD 10

COLUMN	SYMBOL	ITEM	SCALING
1-40	FMAS(I,ITT) = AN ASCENDING ORDERED TABLE OF FRAGMENT MASSES USED IN THE VULNERABILITY DATA FOR ELEMENT I. (ITT = 1,NFMS)		8F5.0

CARD 11

COLUMN	SYMBOL	ITEM	SCALING
1-70	VEL(I,JTT) = VELOCITY (JTT= 1,NVEL)		14F5.0

CARD 12

COLUMN	SYMBOL	ITEM	SCALING
1-30	ELV(I,KTT) = AN ASCENDING ORDERED TABLE OF FRAGMENT STRIKING ANGLES USED IN THE VULNERABILITY PATH FOR ELEMENT I (KTT = 1,NELVS)		6F5.0

CARD 13

COLUMN	SYMBOL	ITEM	SCALING
1-30	VEETBL(I,ITT,KTT) = MINIMUM LETHAL FRAGMENT VELOCITY FOR TARGET ELEMENT I, ZONE N, FRAGMENT MASS M. ZONE N, FRAGMENT CLASS M-(M=1,NGKS)		6F5.0

CARD 14

COLUMN	SYMBOL	ITEM	SCALING
1-10	A = CONSTANT DEFINING CASUALTY		F10.0
11-20	B = CONSTANT DEFINING CASUALTY		F10.0
21-30	C = CONSTANT DEFINING CASUALTY		F10.0

APPENDIX II

GURNEY EQUATION CORRECTION FACTOR

In developing the algorithms for this modification, it was discovered that there is a degree of uncertainty about the Gurney formula. The Gurney formula, derived in Reference 4, predicts the fragment fly-off velocity of a warhead as a function of explosive characteristics and charge-to-metal ratio. The uncertainty concerns the accuracy of the fly-off velocity prediction. Several publications (Reference 2, for example) suggest using 70 or 80 percent of the value predicted by the Gurney equation. There is some disagreement in this uncertainty, however. References 5, 6, and 7 mention that for a warhead with a length-to-diameter ratio of less than 2, the Gurney formula yields high results and as a result should not be adjusted. In an attempt to include recent and accurate state-of-the-art technology in this modification, an investigation was performed to determine the most recent and the most accurate algorithm to predict fragment fly-off velocity.

Reference 5 presents some experimental data illustrating the variation of fragment fly-off velocity as a function of warhead length-to-diameter ratio. However, a representative equation is not given; therefore the results cannot be easily utilized. The purpose of this appendix is to derive such an equation.

The graphical data in Reference 5 approximate the general form of an inverse exponential curve approaching unity. For this reason, the following general equation was chosen to fit the data:

$$Y = 1 - ae^{bX} \tag{II-1}$$

where Y is the dependent variable (correction factor) and X is the independent variable (length-to-diameter ratio). The constants a and b must be determined and they can be computed using the least squares method.

Equation (II-1) must be transformed into a polynomial equation before the least squares method can be applied. This can be done by using the following transformation,

$$1-Y = ae^{bX}$$

$$\ln(1-Y) = \ln a + b\,X \ln e \tag{II-2}$$

$$\ln(1-Y) = \ln a + b\,X$$

Equation (II-2) is in the first order polynomial form,

$$U = A + B\,V \tag{II-3}$$

where A and B are constants and U and V are variables. In regression analysis, it is shown that an equation can be fit to a set of data points in the form of equation (II-3) by use of the normal equations,

$$\Sigma U_i = nA+B\Sigma V_i$$

and

$$\Sigma U_i V_i = A\Sigma V_i+B\Sigma V_i^2$$

where n (i = 1, ... , n) is the number of data points, A and B correspond to the A and B in equation (II-3), and (U_i, V_i) is the ith data point. Solving for A and B,

$$A = \frac{\Sigma U_i}{n} - B\frac{\Sigma V_i}{n}$$

$$B = \frac{n\Sigma V_i U_i - \Sigma U_i \Sigma V_i}{n\Sigma V_i^2 - (\Sigma V_i)^2} \tag{II-4}$$

By applying equations (II-4) to equation (II-2), the constants in equation (II-1) can be determined

$$b = \frac{\Sigma X_i \ln(1-Y_i) - [\Sigma \ln(1-Y_i)](\Sigma X_i)}{n\Sigma X_i^2 - (\Sigma X_i)^2}$$

$$a = \exp\left(\frac{\Sigma \ln(1-Y_i) - b\Sigma X_i}{n}\right) \tag{II-5}$$

A computer program was written to perform these calculations. The Gurney equation correction factor, γ, was found to be

$$\gamma = 1-.4486\ e^{-1.2345(L/D)} \tag{II-6}$$

The program source statements and the output are listed on the next following computer printout sheets.

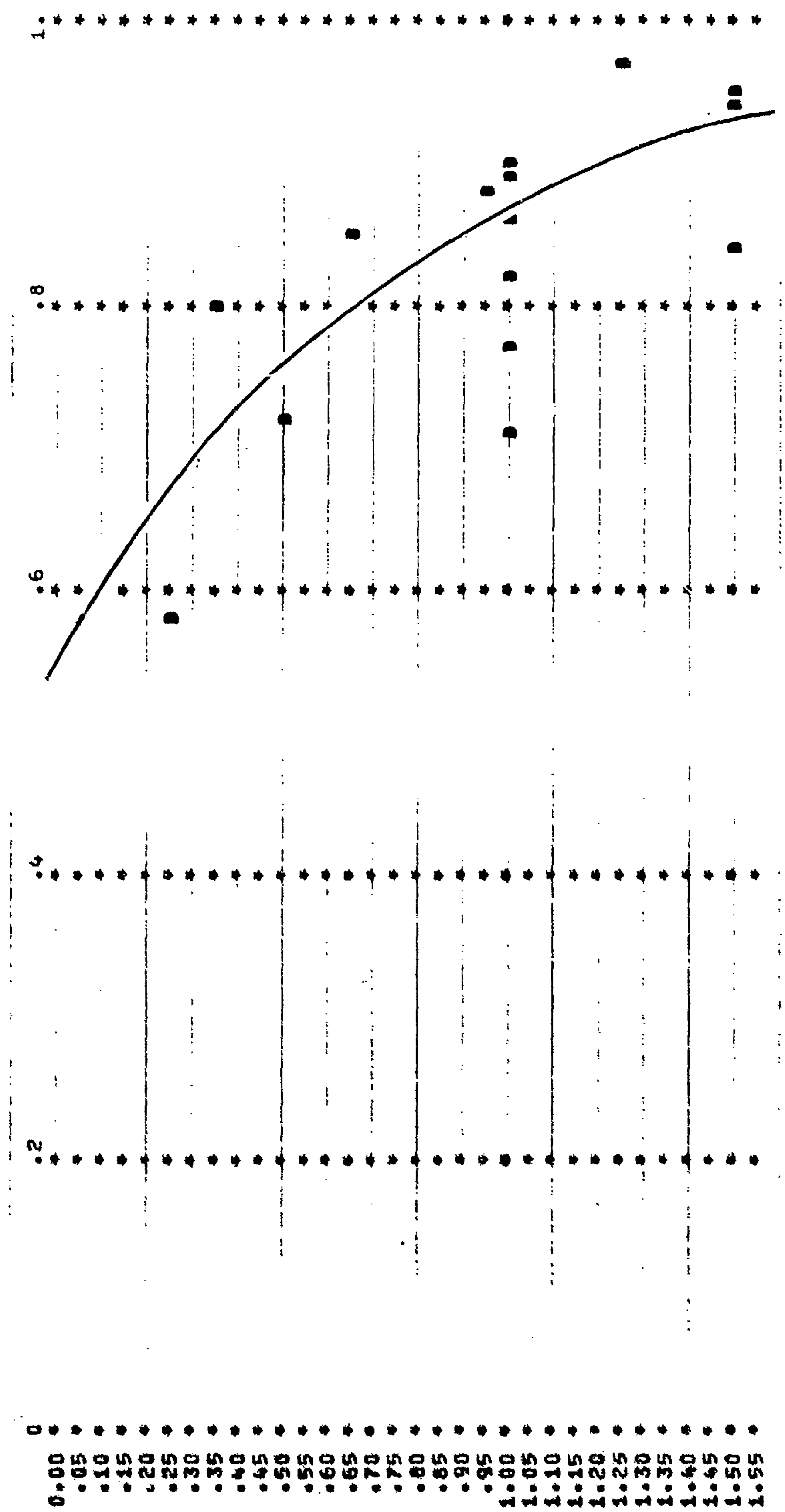
```
      PROGRAM GURFAC(OUTPUT,INPUT,TAPE5=INPUT)
      DIMENSION X(100),Y(100),LINE(100)
    1 FORMAT(5F10.3)
    2 FORMAT(2F10.3)
   20 FORMAT(1H1,5X,  *INPUT DATA(D)     COMPUTED VALUE(C)*)
   21 FORMAT(8X,*X*,9X,*Y*,8X,*L/D*,6X,*GAMMA   GAMMA-Y*,/)
   22 FORMAT(1H1,//,6X,*0*,18X,*.2*,18X,*.4*,18X,*.6*,18X,*.8*,17X,*1.*)
   31 FORMAT(1X,5F10.3)
   35 FORMAT(///,19X,*COMPUTED EQUATION--*,/,19X,*GAMMA = 1.0 -*,F8.5,*
     1EXP(*,F8.5,* L/D)*,///////,19X,*INPUT DATA FROM REFERENCE 5, PG 4-
     2183.*)
   50 FORMAT(1X,F4.2,1X,100A1)
   65 FORMAT(1H+,5X,100A1)
      READ(5,1) YMAX,YMIN,DELX,XMAX,XMIN
      ASSIGN 25 TO M
      CALL EOF(M)
C       INPUT
      N=1
   10 READ(5,2) X(N),Y(N)
      N = N +1
      GO TO 10
C       SUM PROPER VARIABLES
   25 SUMLNZ = 0.
      N = N -1
      SUMX = 0.
      SUMX2 = 0.
      SMLNZX = 0.
      DO 15 I = 1,N
      Z = 1.-Y(I)
      SUMLNZ = SUMLNZ+ALOG(Z)
      SUMX = SUMX + X(I)
      SUMX2 = SUMX2 + X(I)*X(I)
   15 SMLNZX = SMLNZX + ALOG(Z)*X(I)
C       COMPUTE CONSTANTS
      AN = FLOAT(N)
      C = (AN*SMLNZX-SUMLNZ*SUMX)/(AN*SUMX2-SUMX*SUMX)
      A = EXP(SUMLNZ/AN - C*SUMX/AN)
C       OUTPUT
      PRINT 20
      PRINT 21
      DO 30 I = 1,N
      YC = 1.- A*EXP(C*X(I))
      YDIFF = YC -Y(I)
   30 PRINT 31,X(I),Y(I),X(I),YC,YDIFF
      PRINT 35,A,C
C       PRINT GRAPH
      PRINT 22
      SPAN = 100./(YMAX-YMIN)
      XX=XMIN
      DO 40 I = 1,100
   40 LINE(I) = 1H
   42 LINE(1) = 1H*
      DO 45 I = 20,100,20
```

```
 45 LINE(I) = 1H*
    IX = IFIX(SPAN*(1.-A*EXP(C*XX)-YMIN) +.5)
    IF(IX.GE.1.AND.IX.LE.100) LINE(IX) = 1HC
    PRINT 50,XX,(LINE(I),I=1,100)
    IF(IX.GE.1.AND.IX.LE.100) LINE(IX)=1H
    DO 55 I = 1,N
    IF(X(I).GE.XX.AND.X(I).LT.XX+DELX) GO TO 60
 55 CONTINUE
    GO TO 75
 60 IX = IFIX(SPAN*(Y(I)-YMIN) +.5)
    LINE(IX) = 1HD
    PRINT 65,(LINE(K),K=1,100)
    LINE(IX) = 1H
    GO TO 55
 75 XX = XX+DELX
    IF(XX.LT.XMAX) GO TO 42
    CALL EXIT
    END
```

INPUT DATA(D)		COMPUTED VALUE(C)		
X	Y	L/D	GAMMA	GAMMA-Y
.150	.630	.150	.627	-.003
.250	.580	.250	.671	.091
.350	.800	.350	.709	-.091
.500	.720	.500	.758	.038
.650	.854	.650	.799	-.055
.950	.880	.950	.861	-.019
1.000	.707	1.000	.869	.162
1.000	.770	1.000	.869	.099
1.000	.824	1.000	.869	.045
1.000	.865	1.000	.869	.004
1.000	.892	1.000	.869	-.023
1.000	.898	1.000	.869	-.029
1.250	.970	1.250	.904	-.066
1.500	.840	1.500	.930	.090
1.500	.938	1.500	.930	-.008
1.500	.950	1.500	.930	-.020

COMPUTED EQUATION--
GAMMA = 1.0 - .44860 EXP(-1.23449 L/D)

INPUT DATA FROM REFERENCE 5, PG 4-183.


0
.2
.4
.6
.8
1.
0.00
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
.70
.75
.80
.85
.90
.95
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55

APPENDIX III

DISCUSSION OF POLAR ZONE ASSUMPTION

It is assumed in this and most similar computer programs that no significant accuracy is lost if the upper polar zone angle (θ_1 in Figure III-1) is represented by the angle computed in Shapiro's formula (θ in Figure III-1). If valid, this assumption will simplify the computations performed within the program. In this appendix, the conditions under which this assumption is valid will be discussed.

Figure III-1 illustrates a cylindrical warhead with the polar zone angle (θ_1) and Shapiro's angle (θ) pictured. For the assumption to be valid, it must be shown that arc length B is very much larger than the sum of arc lengths A and C. That is, it must be shown that assuming the fragments emanate from the center of the warhead is an accurate approximation of the real case in which the source of the fragments is the side of the warhead and not a point at its center.

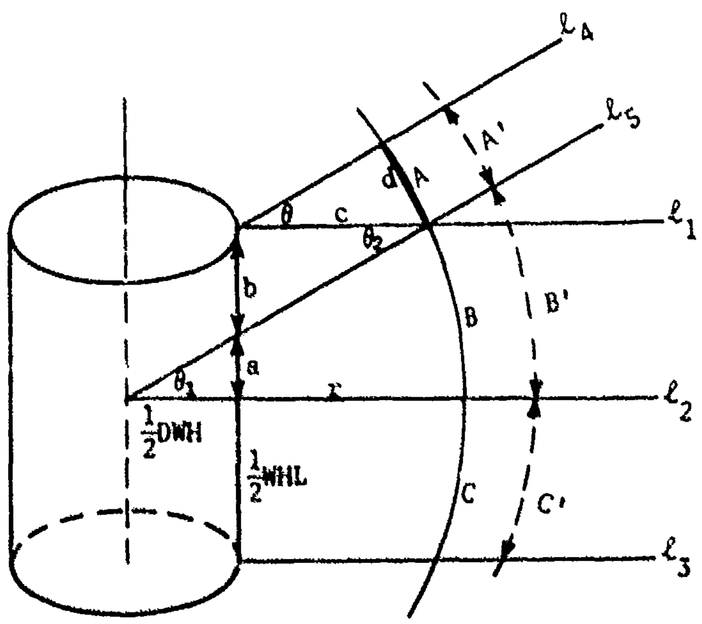


Figure III-1. Polar Zone Assumption

This assumption can be stated as:

$$B \approx B+A+C,$$

or (III-1)

$$B >> A+C$$

Since $l_1 || l_2 || l_3$ and $l_4 || l_5$

some obvious identities are

$$\theta = \theta_1 = \theta_2 \qquad A \approx d$$

$$0 < \theta < \frac{\pi}{2} \qquad B = r\theta \qquad C \approx \frac{1}{2} WHL$$

Now equation (III-1) can be stated as

$$r\theta >> d + \frac{1}{2} WHL \tag{III-2}$$

The length, d, can be determined from the following

$$\tan \theta_1 = \frac{a}{\frac{1}{2} DWH}$$

(III-3)

$$a = \frac{1}{2} (DWH) \tan \theta$$

now

$$b = \frac{1}{2} WHL - a$$

$$= \frac{1}{2} WHL - \frac{1}{2} (DWH) \tan \theta_1 \tag{III-4}$$

$$\tan \theta_2 = \frac{b}{c}$$

so

$$c = \frac{b}{\tan \theta_2}$$

$$= \frac{\frac{1}{2} WHL - \frac{1}{2} DWH \tan \theta_1}{\tan \theta_2} \tag{III-5}$$

$$\sin\theta = \frac{d}{c}$$

$$d = c \sin\theta \qquad \text{(III-6)}$$

$$= \frac{1}{2}\,\frac{WHL-(DWH)\tan\theta_1}{\tan\theta_2}\sin\theta$$

Since $\theta = \theta_1 = \theta_2$

$$d = \frac{1}{2}\,\frac{WHL - (DWH)\tan\theta}{\tan\theta_2}\sin$$

$$= \frac{1}{2}\,[WHL - (DWH)\tan\theta]\cos\theta \qquad \text{(III-7)}$$

$$= \frac{1}{2}\,[WHL\,(\cos\theta) - DWH\,(\sin\theta)]$$

Combining equation (III-2) and (III-7)

$$\theta\, r \gg \frac{1}{2}\,[WHL\,(\cos\theta) - DWH\sin\theta + WHL]$$

$$\gg \frac{1}{2}\,[WHL\,(1 + \cos\theta) - DWH\sin\theta] \qquad \text{(III-8)}$$

Since θ is constant for a given situation,

$$r \gg \frac{1}{2\theta}\,[WHL\,(1 + \cos\theta) - DWH\sin\theta] \qquad \text{(III-9)}$$

Equation (III-1) has now been transformed into equation (III-8). The simulation of fragments as emanating from the center of the warhead becomes more accurate as the distance of the target from the warhead and the fragment spray angle become larger.

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13. ABSTRACT

This report documents the Cylindrical Warhead Design Optimization segment of the Weapons Optimization Techniques computer program. This segment enables the user to optimize or parameterize the basic design parameters of a theoretical warhead for a given target or set of targets. The warhead lethality is determined as a function of the basic design parameters: warhead weight, warhead volume, warhead diameter, charge-to-metal ratio, fragment mass, ratio of warhead length to diameter, and fragment height-to-width ratio. This segment can also optimize or parameterize height of burst, terminal velocity, impact angle, and fragment spray angle.

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